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# AEROMEDICAL AND BIOLOGICAL CONSIDERATIONS OF FLIGHT ABOVE THE ATMOSPHERE

BY COLONEL PAUL A. CAMPBELL, USAF (MC)

SUMMARY

New altitude and speed records indicate ever-increasing trends toward the possibility of flight above the atmosphere. Basic biological problems group themselves into three primary categories: those associated with the attainment of high speed and penetration of the atmosphere at those speeds; those resulting from loss of the life-sustaining qualities of the earth's atmosphere; and those resulting from loss of protection afforded by the filtration qualities of the atmosphere. These categories are discussed.

## Introduction

During August 1953 Lt. Colonel Marion E. Carl flew the Douglas D-558-2 Skyrocket to an altitude of 83,235 feet. This feat is significant for those of us interested in the possibilities of flight above the atmosphere when we consider that at zenith the ambient barometric pressure was only 18 mm. of mercury. Thus more than 97 per cent. of the mass of the atmosphere lay beneath Colonel Carl. When these figures are turned about they indicate that less than 3 per cent. of the mass of the atmosphere lay above although, of course, the distance to the absolute limits of the atmosphere remained great.

Almost as significant as Colonel Carl's flight was a flight at Holloman Air Force Base, New Mexico in May 1952 of two monkeys and two mice in an Aerobee rocket adapted for aeromedical studies under the supervision of Dr. James Henry of the Aero-medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio. At zenith that rocket reached an altitude of 36 miles or approximately 190,000 feet. At that altitude the average barometric pressure was approximately 0·321 mm. of mercury implying that less than 0·05 per cent. of the mass of the atmosphere remained above the rocket. Of interest incidental to that flight are the following data:—

(*a*) Duration of flight was about 16 minutes and 40 seconds.
(*b*) Top speed was 1,909 m.p.h.
(*c*) Top thrust in "*g*" units was 14 *g* lasting for a period of 2½ seconds.
(*d*) Prolonged thrust in *g* was 2½ to 4 *g* lasting 45 seconds.

Both monkeys survived without apparent injury. They are in a Washington Zoo to-day alive, well, and apparently unaffected by their epochal flight.

Some four years ago a two-stage rocket known as the WAC Corporal reached an altitude of approximately 250 miles (1,320,000 feet). From a functional point of view that rocket at the peak of its journey was in space in that the mean free path of the remaining particles of air at that altitude was in the neighbourhood of 2–4 miles. This condition, I have been told, represents a more complete vacuum than has been created in any of our laboratories.

These and other events of the past few years indicate that travel above the atmosphere in a medium without drag other than the pull of gravity is within the range of the feasible. This present year may well be a turning point in our thinking from "Is flight above the atmosphere feasible?" to "Exactly what are the requirements for its accomplishment?" If an unmanned vehicle can be sent into those reaches then it certainly will not be long before man will wish to accompany the vehicle. If rapid scientific progress in the field continues, as most of us in this group believe, then an era of travel above the atmosphere is in the not too distant future.

As a physician and biologist my interests and thus the scope of this paper are limited to the aeromedical and biological aspects of such flight, and as my knowledge of American studies far outweighs my knowledge of work done in other countries please forgive me if I seem to place too much emphasis on the work of my countrymen. As a starting point it is of interest to have a quick panorama of the effort in space biology which has been exerted in the United States during the postwar period. In 1947 Brigadier General H. G. Armstrong (now Major-General) was the Commandant of the USAF School of Aviation Medicine. He, with a group of scientists, envisaged the implications of the rapid advances in aviation and rocketry and at the same time recognized many of the biological implications which would most certainly require circumvention if man were to travel above the atmosphere. As a consequence of his convictions he established a Department of Space Medicine at the USAF School of Aviation Medicine and organized scientists including Drs. Hubertus Strughold, Heinz Haber, Konrad Buettner and others, for the purpose of delineating the biological barriers which might be encountered. In the autumn of 1948 a group of interested scientists gathered at the USAF School of Aviation where the problems were discussed.[1]

This symposium was in turn followed by a larger symposium held at the University of Illinois in Chicago, March 3, 1950. A book entitled *Space Medicine* resulted from that meeting. The following summer a Space Medicine Branch of the Aero-medical Association was organized in Chicago at a meeting of the Aero-medical Association. Successive meetings of this section have been held each year since 1950. The membership list has undergone rapid expansion as has the interest displayed. Whereas only 35 scientists attended the 1950 meeting more than 85 attended the 1954 meeting. Whereas only three short papers were given at the first meeting, nine excellent papers were presented at the last.

Probably the most important single event which has occurred in the United States during this particular era was a four-day symposium held under the combined sponsorship of the USAF School of Aviation Medicine and the Lovelace Foundation for Medical Education and Research. That meeting was

held November 6–9, 1951. The *Proceedings* of the meeting were published under the editorship of C. S. White and O. O. Benson, Jr. in the 600-page text *Physics and Medicine of the Upper Atmosphere.*[2] This excellent book is certainly the leading American reference on the subject of our interest. Of incidental interest, more than 2,100 copies have been sold.

Through this growth period increased laboratory facilities were organized at various points in the United States. The group in the Space Medicine Department of the USAF School of Aviation Medicine continued their theoretical studies. The group at the Aero-medical Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio developed their biological rocket programme through which fruit flies, mice and later hamsters and monkeys were sent aloft in balloons and/or rockets. During this time telemetering equipment was perfected for on-the-ground recording of various phenomena occurring in and outside the rocket as well as physiological changes occurring in the animals. An Aero-medical and Space Biological Laboratory was built at Holloman Air Force Base, New Mexico for the purpose of furnishing laboratory facilities for that rocket test site. More recently high altitude balloon flights have carried small animals for studies concerning biological effects of cosmic radiation. The U.S. Naval School of Aviation Medicine at Pensacola, Florida and the U.S. Army Medical Research Laboratory, Fort Knox, Kentucky have each made their own definite contributions to the rapidly increasing fund of knowledge of space biology in the United States. Several of these laboratory facilities have sublet contracts covering portions of their projects to universities and civil technical groups thus expanding the base of the studies into non-military laboratories. Some of our lay publications have sponsored symposiums. Some of our astronomical observatories have added biological sections to their seminars and their symposia on space flight. One should pause to point out here that a primary deterent has been the effort which had to be expended to keep the programme on a realistic basis and to prevent irresponsible reporting from casting an aura of ridicule about it.

**Biological Problems**

Now to return to the biological problems which must be faced. Since the birth of aviation just half a century ago progress in development has been a constant race between man and machine for altitude and speed superiority. From time to time human limitations have interjected altitude or speed ceilings and from time to time it has been the limitation of the machine which has produced the barrier. Historically some of the barriers have appeared insurmountable for considerable periods of time. All of the barriers, however, have, so to speak, lowered their bars as they were met head-on by scientific and industrial developments. The machines have been so altered that the Wright Brothers' aircraft of December 17, 1903 bears little resemblance to that of to-day. However the fundamental physiology of man has changed not one iota.

To review a few of the major barriers which have appeared insurmountable from time to time, let us turn to the following table in which the first column defines the barrier, the second column states the problem and the third column shows the development by which the barrier was circumvented.

TABLE I

BARRIERS

| Apparent Barrier | Problem | Actual Solution |
|---|---|---|
| Altitude 15,000 to 18,000 ft. | Anoxia | Oxygen systems |
| Altitude 38,000 to 42,000 ft. | Anoxia in spite of 100 per cent. breathing oxygen | Pressure breathing<br>Pressure cabins |
| Altitude 33,000 ft. upward | Aeroembolism | First pre-breathing of oxygen<br>Later pressurized cabins |
| Altitude 70,000 ft. up | Limit of economical pressurization | Sealed cabin |
| Speed of sound | Loss of control<br>Buffeting<br>Disintegration of aircraft | Redesign of airfoil and propulsion |

As is well-known to all of us *none* of the so-called barriers, most of which have involved human limitations, have impeded the progress of aviation for more than a very short period of time.

At present *no* completely insurmountable biological barrier appears on our horizon; however, there are a number of problems which will require a large amount of study by the biologists and the engineers before flight above the atmosphere can become commonplace. The biological and medical problems can, generally speaking, be resolved into three categories.

First are those resulting from the attainment of high speed and the necessity of penetration of the earth's atmosphere at these speeds both on the outward and inward legs of their flight; second are those resulting from loss of the life-sustaining qualities of the atmosphere and third are those resulting from loss of the protection afforded by the filtration qualities of the earth's atmosphere.

Since the presence or the absence of the atmosphere which surrounds our Earth accounts in one way or another for most of our biological problems, let us turn first to its structure. According to the structure of the atmosphere as present conceived by geophysicists, density decreases rapidly as altitude is attained. About 90 per cent. of the mass of the atmosphere lies within the first 10 miles above the earth, and almost 99 per cent. of it lies within the first 20 miles. The remaining 1 per cent. may extend to 6,000 or possibly even 60,000 miles depending upon the criteria applied. From a practical standpoint less than one ten-thousandth of one per cent. remains at 90 miles. Functional space is considered by several scientists to begin in the neighbourhood of 120 miles of altitude[3] as at this level significant drag or friction to passage is lost almost in its entirety. In fact drag is so slight at this height that according to estimations months of orbital travel around the earth would result in only a few inches of lost altitude.

Ambient temperature decreases with altitude averaging about 1° F. for each 300 feet until, depending on latitude, time of year and so forth, an altitude of

about 7 miles is reached. The temperature above this altitude remains relatively constant at −55° C. (−67° F.) to about 20 miles at which altitude it begins to warm considerably, reaching approximately 76° C. (170° F.) at 31 miles. Again temperature remains more or less constant for the next 7 miles; then from 30–50 miles of altitude it drops to −33° C. (−27° F.) and remains constant for a few miles. At about this level the atmosphere becomes so rarefied that heat can no longer be transferred to it. Consequently the temperature of any object is that of the heat from radiation which is mostly of solar origin. Thus temperature depends upon the reflective or absorptive characteristics of the object. Temperatures may reach extremes depending upon these characteristics of the exposed surfaces—that is, whether they are bright or dull and whether they are reached by the direct rays of the sun or are in their own or the earth's shadow.

Sky brightness decreases as a function of altitude. Although the sky is as black as the night sky at about 70–80 miles each reflecting object will become a new light source to reflect the unattenuated light of the sun. This phenomena, of course, is due to the absence of light dispersion by the remaining atmosphere.

**Problems Associated with High Speed and Atmosphere Penetration**

Let us turn now to our first problem category—those problems associated with the attainment of high speed and the high speed penetration of the atmosphere. Rocket power plants, which will probably furnish the first feasible power for flight above the atmosphere, are characterized by a very great release of energy over a very short period of time. After power application the vehicle must, so to speak, coast for relatively long periods. One German World War II V–2 rocket burned only 71 seconds to reach an altitude of 60 miles and a speed of 3,600 miles per hour. Through the energy thus imparted it travelled in the neighbourhood of 200 miles.[4] High velocity flight through the atmosphere results in high aircraft skin (shell) temperatures. High structural temperatures require insulation and cooling for protection of pilot and passengers. The skin temperature of one V–2 rocket[5] was measured at 647° C. (1196° F.). Cooling without the addition of prohibitive weight or power loss is a relatively serious problem. Now what are man's limitations or, stated in another way, his tolerances of environmental temperatures? The extended work of C. L. Taylor, W. V. Blockley, J. Lyman, N. J. McConnell and others indicates that with minimal air movement, while wearing light clothing and at rest or at no more than light manual activity, time tolerance averages are in the neighborhood of 70 minutes at 70° C. (158° F.); 55 minutes at 80° C. (176° F.); 40 minutes at 90° C. (194° F.) and 20 minutes at 115° C. (239° F.).

High-speed penetration of the atmosphere from the biologist's point of view probably should take place through the atmosphere's thinnest dimension which, of course, is straight up. Parasitic boost or assist by carrying the rocket craft upward in or on a mother aircraft (as was done in the case of the Douglas Skyrocket) may be quite helpful from many points of view not least of which is initiating the journey with a cold aircraft skin.

It is rather generally accepted that speeds associated with travel above the atmosphere must be high as the vehicle must of necessity be of projectile

character. As is well-known, speed *per se* seems to have no effect upon the human organism. However acceleration necessary to reach high velocity and deceleration necessary to return to the static condition both *do* affect the human. Similarly fractional gravity states or the gravity-free state which can be expected if high velocities are attained and/or during manoeuvres involving Keplerian parabolic flight patterns[7,8] will effect the human. Likewise it must be remembered that human reaction time, a rather well-defined physiological constant, has remained practically unalterable through the evolutionary period of man. As a consequence manoeuvres at high-speed will involve several problems.

Of these let us first take up the problems associated with acceleration and deceleration. A series of initial acceleration values sufficient to reach escape velocity and their required time of application have been stated by H. Haber and others to be approximately as in Table II.

TABLE II

| Acceleration Physiologically Effective | Duration of Acceleration |
|---|---|
| 3*g* | 9 min. 31 sec. |
| 4*g* | 6 min. 21 sec. |
| 5*g* | 4 min. 45 sec. |
| 6*g* | 3 min. 48 sec. |
| 7*g* | 3 min. 10 sec. |
| 10*g* | 2 min. 6 sec. |

In studies at the Aero-medical Laboratory at Wright Field, Ballinger and co-workers[9] found accelerations up to 10 *g* were tolerated by untrained individuals for comparable periods of time without *g*-suit protection if they were in semi-prone and supine positions. During acceleration of these magnitudes and while in the semi-prone and supine positions the individuals they studied were able to converse in monosyllables, their vision was clear, they were mentally alert, were able to respond to visual and auditory signals and they retained relatively unimpaired mobility of their hands, wrists and ankles. During such high degrees of acceleration or deceleration it will of course be necessary to fix the heads of the occupants in such a position that a line representing the direction of acceleration or deceleration will bisect at right angles a line drawn between the two labyrinths or semi-circular canal systems of the inner ear. These precautions will be necessary if disabling vertigo resulting from the so-called Corioles reaction is to be avoided.[10]

As mentioned previously consternation has been expressed recently by a number of scientists concerning the effects of subgravity or gravity-free states which result from escape velocities or parabolic flight patterns. The resultant serious problems appear to be the possibilities of disorientation and those of lack of muscular co-ordination. As is well-known three physiological systems are involved in human orientation or equilibration. Briefly these are:

(1) the visual apparatus,
(2) the semi-circular canal systems of the inner ear, and
(3) the kinesthetic system.

For purposes of this presentation it is sufficient to explain that the semi-circular canal system is gravity oriented; the kinesthetic system is tension oriented, but gravity usually acts as one of the moments of force; the visual apparatus is in no way dependent on gravity. These three physiological systems make up the so-called orientation triad. The proper function of two of the systems has been considered necessary for efficient orientation.[10] As absence of the gravity vector interferes with the operation of two of the components, doubts were expressed. However from the meagre research available on the subject it appears that loss of the gravity stimulus by the semi-circular canals and the kinesthetic systems can be compensated through conditioning if vision and visual clues are present. Vision appears to be the dominant factor of the triad. So far as I know, no human has been in the gravity free state for more than a period approximating 30 seconds. Two pilots, S. Crossfield[11] and Major Charles Yeager have reported such experiences. They described unusual sensations but felt they were in no way disabling. Considerably more experience with this phenomena will be required before the problem can be completely assessed.

Now to return a moment to the flight problems posed by physiological and psychological reaction times. The world literature is filled with discourses on this subject. In the United States papers on the subject have been written by many authors including Campbell,[12] Strughold [13,14] and others.

The entire matter can probably be summarized with the statement that human reaction time for the simplest reflex activity is of the order 2/10 of a second. It is considerably longer for more complex types of activity especially if the times of perception and cerebration are added. For our purposes we must also add the time necessary for translation of human activity into aircraft response, in other words the reaction time of the controls. Consequently when take-off and landing manoeuvres are required, they will have to be performed at speeds not too much greater than those presently attained. As our science of automatic control improves, human reaction time will probably be less and less a problem. The solution must rest with the engineers.

**Loss of Life-Sustaining Qualities of the Atmosphere**

Now let us turn to the second category—those problems resulting from loss of the life-sustaining qualities of the friendly atmosphere which surrounds our earth. These qualities are a function of the substance of the atmosphere and the pressure it exerts. The essential atmospheric substances are oxygen, carbon dioxide, nitrogen and water vapour. Without oxygen we could not live. Without nitrogen and carbon dioxide plant life upon which we must depend would be vastly altered. Without water vapour neither plant nor animal life on this earth would be possible.

Let us first look at the essential substance, oxygen. The biological stress resulting from the lowering of the partial pressure of the oxygen supplied to the lungs is given the medical term *hypoxia*. Lowering of the partial pressure at which oxygen is delivered to the alveolar sacs of our lungs results from the decrease in barometric pressure which in turn is a function of altitude.

Barometric pressure decreases rapidly between sea level and 100,000 ft. of altitude—from 760 mm. of mercury to 8 mm. of mercury. In pounds per square inch—from 14·7 pounds to 0·155 pounds. From 100,000 ft. upward the pressure continues to decrease rapidly and at 200,000 feet it must be measured in microns of mercury—238·6 microns to be exact and at 300,000 ft. 5·4 microns. Although the percentage of oxygen in the atmosphere remains at a level of approximately 21 per cent. throughout the major portion of the atmosphere, at about 10,000 ft. the barometric pressure is reduced to 522 mm. of mercury. As a consequence there is a lowering of the partial pressure of oxygen in the alveolar sacs of the lungs to approximately 60 mm. and in the blood which courses through the walls of these small sacs—a saturation of about 90 per cent. Ninety-six per cent. saturation of the blood is about normal average and little in the way of symptoms are produced at an altitude of 10,000 ft. However, this level is considered to be about the upper limit at which the breathing of ambient air alone is not deleterious. As we proceed upward from 10,000 ft., blood oxygen saturation falls off rapidly. At an altitude of 18,000 ft. oxygen saturations of the blood reach about 70 per cent., a level of deprivation serious enough to produce unconsciousness.

Studies of the average time of useful consciousness[15] as a function of decreasing altitude indicates that useful consciousness while breathing ambient air represents no particular problem until levels of over 15,000 ft. are reached. At 20,000 ft. it is still a matter of minutes until the advent of unconsciousness; at 25,000 a little less than 3 minutes; at 30,000 ft. 70 seconds; at 40,000 ft. 23 seconds and from 50,000 ft. upward about 15 seconds.

To overcome oxygen deprivation resulting from the decreased density of the atmosphere, aeromedical scientists and aviation engineers have proceeded step by step through five stages in the development of apparatus or procedures which could make oxygenation for flight above the atmosphere possible. The first stage was that of the simple utilization of outside or ambient air. This allowed pilots to fly somewhat above 10,000 ft. without ill-effect. However at a level of 18,000 to 20,000 ft. pilots became unconscious until they learned to take 100 per cent. oxygen from a tightly fitted mask in the second stage of development. This in turn lifted their ceiling to approximately 39,000 ft. In the third stage the breathing of oxygen under a small amount of positive pressure added a few thousand feet of altitude to approximately 42,000 ft. This ceiling is about the limit which can be expected from oxygen systems alone. For the fourth stage the advent of cabin pressurization allowed an altitude of 70,000 to 80,000 ft. to be reached, but at about that altitude the atmosphere becomes so rarefied that adequate compression in terms of weight of the compressor becomes uneconomical. Above that altitude the sealed cabin representing the fifth stage of development became a requirement. Such a cabin must have an adequate initial pressure, the extent of which depends on whether or not a supplementary oxygen system with mask is employed. If flight times of more than a few hours are to be involved or if an oxygen supply and oxygen mask are not to be used, at least some of the components of breathing air for synthesis and pressurization at an optimal pressure must be employed. For trips lasting for long periods of time, the air would of necessity have to be

cleaned from time to time to have its impurities removed, to be followed by replacement of essential substances in proper proportion. This problem, as can be easily seen, requires considerable research.

Lowering of barometric pressure results in another biological effect known as decompression sickness or "bends." This pathological entity is due to the release of nitrogen from the blood into the body tissues and closed cavities as outside pressure is decreased. Although the occurrence of bends and the site at which it occurs has certain of the aspects of chance phenomena it is certainly correlated with *rapidity* of the reduction of environmental barometric pressure as well as the duration of stay at altitude. Symptoms may occur as low as an equivalent of 23,000 ft. of altitude. At an altitude of 63,000 ft. the ambient pressure, 47 mm. Hq., is equal to the vapour pressure of water at body temperature, a condition resulting in true boiling.[17]

With this in view it can be seen that above the atmosphere explosive decompression which would follow the loss of a cabin door or a window or the penetration by a solid object could be catastrophic unless some sort of a pressure suit with an integrated oxygen supply were being worn. Fifteen seconds would be about the maximum time of useful consciousness at these levels.

**Loss of Filtration Qualities of the Atmosphere**

Now to turn to our third and last problem category, that embracing those problems resulting from the absence of the *filtration* qualities afforded by our atmosphere.[18] Under normal circumstances the atmosphere under which we live protects us first from the more destructive portions of the ultra-violet spectrum, second from the more undesirable portions of the infra-red spectrum, third from practically all of the primary particles of cosmic radiation and fourth from meteors and meteoritic dust. These filtration qualities are due primarily to the mass of the atmosphere, the presence of water vapour, ozone and through the process of oxygen dissociation. Water vapour is a comparatively effective filter of the infra-red portion of the spectrum above 1·4 microns and a somewhat less effective filter in certain areas below 1·4 microns.

Protection against the erythema-producing portion of the ultraviolet spectrum is afforded by a layer of ozone occurring at altitudes of 11 to 20 miles (60,000 to 105,000 ft.) depending on the time of day. This ozone layer is the result of photochemical molecular oxygen dissociation followed by one molecule of oxygen uniting with one atom of oxygen to produce $O_3$. Ultraviolet radiation of the sun produces the photochemical effect. The layer forms an effective filter for ultraviolet emanations between 210 and 310 mu. The concentration of ozone of the atmosphere begins to increase at an altitude of about 20,000 ft. At altitudes in the neighbourhood of 70,000 ft. the concentration is such that if all the ozone of a vertical section one kilometer in thickness were completely compressed it would represent a sheet of relatively pure ozone of the order of 0·019 cms. in thickness. If an amount of ozone of this order were compressed into an aircraft cabin it could be quite toxic. The sealed cabin type of aircraft is, of course, the answer to that specific problem. Still another protective factor results from the dissociation of oxygen from its molecular form to the atomic form. This phenomena occurs from 75 miles (400,000 ft.) upward and is

responsible for filtration of ultraviolet emissions below 210 mu. Sealed cabin craft can, of course, be rather simply shielded against ultraviolet emissions by the shell and the proper selection of window material.

Such simple shielding, however, cannot be applied for protection against cosmic radiation and the meteoritic substances. Dr. L. R. Shepherd[19] presented an excellent analysis of this situation both from the standpoint of its physics and its biology. It would be presumptive on my part to enter into the subject other than to say for completeness of my presentation that cosmic rays appear to be ultra-high-speed particles of extra-terrestrial origin. They possess energy measured in billions of electron volts and at least some of the particles are capable of producing nuclear disintegration. Secondary rays, tertiary rays and mesons are produced after entrance into the atmosphere and at times produce cosmic ray showers in the denser parts of the atmosphere. Cosmic ray activity due to the filtration effect of the atmosphere decreases as the surface of the earth is approached, and at sea level reaches a value of the order of three one-hundredths of that present in the ozone layer. The few cosmic rays that strike the surface may have sufficient energy to penetrate several hundred feet into it. There are still tremendous gaps in our knowledge of the biological effects of primary cosmic particles, but it is believed that they act similarly to radiation of the alpha particle type with quick energy dissipation and resultant high concentrations of ion pairs along short tracks. Among the most intriguing approaches to the problem of the biological assay of the effects of cosmic radiation was work described last March to the Space Medicine Branch of the Aero-medical Association by Dr. Herman B. Chase.[20] In the preliminary report of his work on cutaneous effects of primary cosmic radiation Dr. Chase discussed the use of the skin as a sort of track plate and dosimeter by observing changes in pigmentation of hair and loss of hair following heavy particle hits on small animals at high altitudes. Before sending animals aloft in balloons he carefully estimated the number of Roentgen units necessary to cause hair follicles to produce white hair under various situations as well as the amount of irradiation which would produce loss of the hair.[21,22]

At the time of his presentation only 8 mice had been studied following flight at high altitude. Track plates accompanying the mice showed evidence of paths due to heavy nuclei and of six star events. Three of the mice showed indications of hits from heavy primaries if one accepts the basic hypothesis of Dr. Chase. Dr. Chase admits that he does not have sufficient studies to draw definite conclusions; however, I believe we all must agree that his approach and preliminary results are interesting.

From the evidence available it would seem that cosmic radiation probably presents the largest question mark of all of the possible barriers to flight above the atmosphere. If flights are just above the limits of the atmosphere the question mark is probably not big.[19] If flights are far above the limits of the atmosphere and are of long duration there are just too many assumptions required to allow assessment at this time.[23]

Let us finally consider the problems of meteors, meteorites and meteoritic dust. Again the protective covering of our atmosphere in the past has shielded us from the major portions of this extra-terrestrial debris through incineration at

levels of 60–90 miles (32,000 to 475,000 ft.). These fragments composed of stone, iron and other substances, most of which are probably no larger than grains of sand, but travel at tremendous velocities. Some travel with speed so great that they have not been captured by the sun's gravitational system. Others travelling at lesser speeds orbit around the sun much as does the earth but in different planes and some in a completely opposite direction. Impact velocities of 6–45 miles per second have been measured. At present there is some difference among the experts concerning the relative magnitude of this problem. However from the calculations of Whipple[24] and Grimminger[25] one can only conclude that danger of penetration of a usual type aircraft skin would be remote in normal periods of travel. Whipple states that the statistical probability of puncture of a vehicle of spherical shape of a diameter of 3 metres and with aluminium skin of a thickness of 0·32 cms. would be of the order of one part in 2,000 per day. Thus in comparison with other hazards incident to such flight the danger is not serious. For long periods of travel above the atmosphere the problem again is quite different.

## Major Requirements

In conclusion let us turn to some of the major requirements for flight above the atmosphere.[18] Cabin pressurization is, of course, an absolute necessity. It is well-known that pressurization of 10 pounds per square inch will afford an environment similar to that of 10,000 feet of altitude in ambient air and therefore, of course, furnishes perfectly livable conditions. Less pressurization would be required if the occupants wore pressure suits with integrated oxygen systems. From the structural point of view 10 pounds per square inch of pressurization is not prohibitive. As previously stated the atmosphere is so rarefied above 60,000 to 70,000 ft. its compression for cabin environment is uneconomical in terms of the weight required. Thus a sealed cabin without exchange with the outside is a necessary requirement. As a consequence the components of breathing air must be carried along synthesized and placed under required pressure inside the craft. If trips are to last any considerable period of time, means must be provided for removal of the accumulated impurities. Again this presents no insurmountable obstacle but still requires considerable research. The wearing of pressure suits for emergency purposes will offer some possibility of survival in case of cabin leak or penetration. However, generally speaking, the most serious problem relative to travel above the atmosphere is that of survival in case of accident. To date the solutions are not adequate, but experience has shown the pioneers of all forms of travel to be willing to consider high degrees of calculated risk as an acceptable occupational hazard.

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# THE ARMSTRONG SIDDELEY "SNARLER"

Photographs of the "Snarler" have been published from time to time but details of the motor have only recently been released. A talk on the development of the "Snarler" is to be given to the London HQ on February 5, 1955, but it is thought that some information on the engine itself might be of interest to members.

The "Snarler" was a liquid propellant rocket motor giving a maximum thrust of 2,000 lbs. and a starting thrust of about 700 lbs. The fuel was a mixture of 65 per cent. methyl alcohol and 35 per cent. water, while the oxidizer was liquid oxygen. The weight of the engine was 215 lbs.

It was intended for boosting climb on an aircraft already powered by gas turbine and it was flight tested during 1950 in the "Hawker" P. 1072 Aircraft. This aircraft was not designed to take a rocket motor and instead of being installed as a compact unit, the components were distributed about the aeroplane where space could be found for them. (It is, of course, one of the virtues of this type of engine that it can be split up in this way if necessary.) Fig. 1 shows different parts of the installation, while Fig. 2 helps us to understand the operation of the control system.

The pilot's controls consisted of two switches and a safety lever which covered the switches unless the rocket was to be fired. The first step towards firing the motor was to move the lever into the "ON" position thereby admitting air to a pneumatic ram which opened a shut-off valve in the liquid oxygen line to the pump. This step could conveniently, but not necessarily, be taken immediately before the tank was filled with oxygen. In that event, as the tank was being filled, oxygen flowed through the pipe lines to the pump and thence to the block of control valves, which it left by means of a bypass valve "B" and returned eventually to the tank. In this way the pipes were reduced to a temperature approaching that of the liquid oxygen, which greatly facilitated priming of the liquid oxygen pump when it was desired to fire the motor. Vapour formed in the system during this cooling-down process was bled off through a valve on the liquid oxygen pump, which was automatically closed as soon as the pump began to deliver liquid at any appreciable pressure.

The situation immediately before firing the motor was this:

The input shaft of the gearbox driving the pumps was being continually driven by the Nene gas turbine but since this gearbox also incorporated a clutch, the pumps were not yet rotating. The liquid oxygen system would have been cooled down as already described.

When the pilot wanted to start the rocket he closed the firing switch, which was the first of the two switches at his disposal. The immediate effect of this switch was first of all to open the isolating valve in the line between the fuel tank and pump. Simultaneously it actuated the solenoid operated air valve 1, which admitted air to pressurizing valves on the fuel and oxygen tanks. These valves opened and allowed low pressure nitrogen to pressurize the tanks to about 5 p.s.i. At the same time air was admitted to an actuator, which applied a band brake to an epicyclic train in the gearbox which had the effect of transmitting the drive from the Nene to the two pumps. The pumps began to

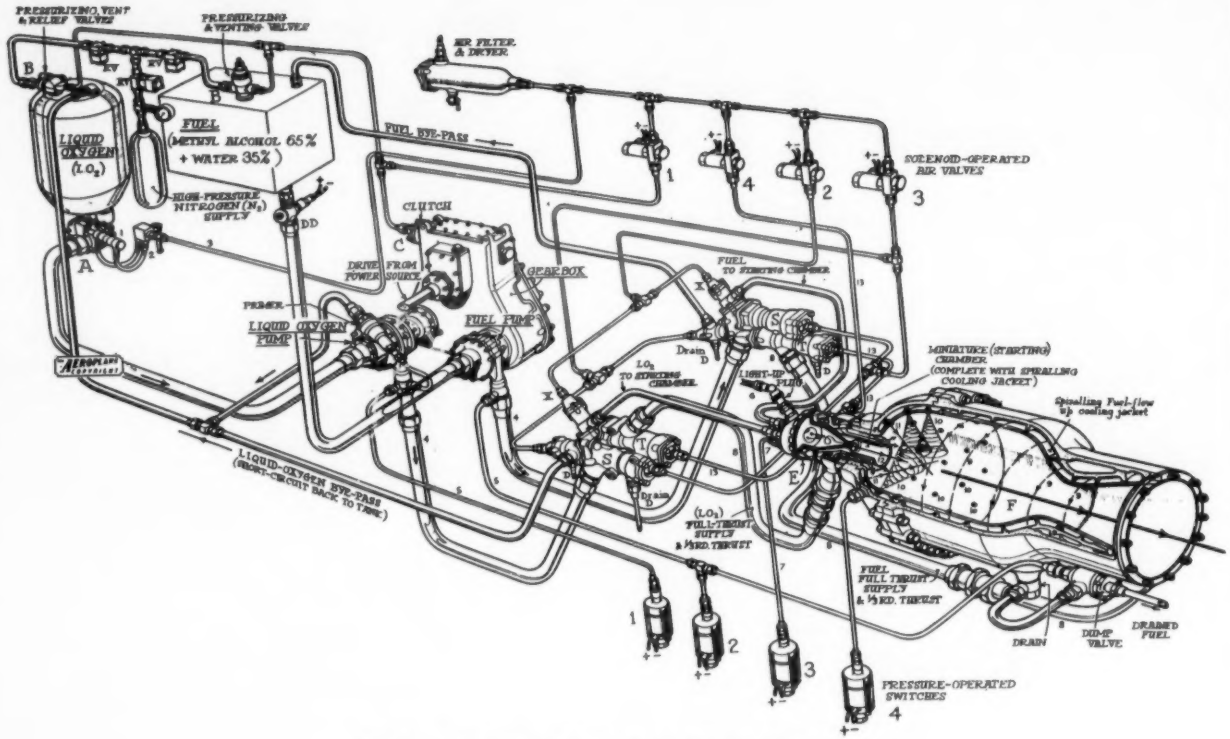


Fig. 1. Diagrammatic layout of the Snarler Rocket Motor
*(Reproduced by courtesy of the Editor of "The Aeroplane")*

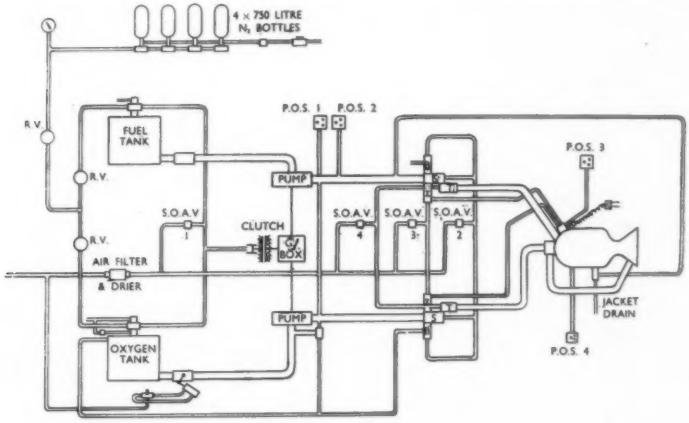


Fig. 2. Operation of "Snarler" control system

rotate and primed almost immediately, propellants being circulated via their respective bypass valves back to the tanks. As soon as both pumps were delivering their correct pressures, the pressure operated switches P.O.S. 1 and 2 closed. These switches were connected in series with the solenoid operated air valve 3 and when the circuit was completed this valve admitted air to the operating pistons in the two igniter stop valves "I," which opened and allowed fuel and oxygen to flow into the igniter on the rocket combustion chamber. At the same time the booster coil, supplying a sparking plug in the igniter, was energized. The propellants injected into the igniter promptly lit and the igniter ran steadily at a pressure of about 100 p.s.i., projecting a small pencil of flame into the main combustion chamber. This igniter pressure was fed to another pressure operated switch 3 which closed and energized the solenoid operated air valve 2. This admitted air simultaneously to the pistons of the bypass valves "B" and the main propellant stop valves "S," thereupon diverting the flow through the bypass pipes to the combustion chamber. It will be seen from the diagram that the propellants had to flow through throttle valves "T" before reaching the combustion chamber. These throttle valves were merely poppet valves with metering holes drilled through their heads and their object was to reduce the propellant flow to that required for starting thrust. When the propellants reached the injector, they were fed into the combustion chamber and lit by the pencil of flame from the igniter. In addition to causing the main stop valves to open, the pressure switch 3 also broke the circuit to the booster coil, thereby cutting the spark.

At starting thrust a pressure of about 100 p.s.i. was generated inside the combustion chamber and this was fed to another pressure operated switch 4, which was connected in series with the second switch in the pilot's cockpit. When that switch was closed the circuit to solenoid operated air valve 4 was

completed and this valve opened and fed compressed air to the throttle valves "T," which opened in their turn and allowed the full propellant flow to be fed to the combustion chamber. The pressure operated switch 4 not only bridged part of the throttle circuit but also broke the circuit to solenoid valve 3, which closed and cut off the supply of propellants to the igniter which was obviously no longer necessary.

This control system was designed so that no step in the starting sequence could proceed unless the previous one was completed. Thus unless both pumps were working properly the igniter could not be lit and unless the igniter was already alight no propellants could be fed into the combustion chamber. These precautions were taken because the makers consider that the greatest hazard in running rocket engines lies in starting them. With this control system it is not possible to get an accumulation of propellants which will explode on starting.

The engine could be switched off and on as required by operating the starting switch. If the throttle switch was left on the restart would be safe because the unit would start at part thrust and run up to full thrust as soon as the combustion chamber pressure operated switch closed. When the unit was shut down the cooling jacket was full of fuel which might dribble into the hot combustion chamber and ignite, producing a large fuel/air flame. To give a clean shut-down a dump valve was fitted to the cooling jacket which drained overboard any fuel remaining in it. During a run this dump valve was closed by pressure fuel bled from the pump acting on a piston in the valve.

Some technical data relating to the "Snarler" are as follows:—

| | |
|---|---|
| Maximum thrust | 2,000 lbs. |
| Average duration | 3 mins. at full thrust |
| Total propellant consumption | 10 lb./sec. |
| Fuel consumption | 5·5 lb./sec. |
| Oxygen consumption | 4·5 lb./sec. |
| Specific impulse | 200 |

*Combustion Chamber:—*

| | |
|---|---|
| Working pressure | 280 p.s.i.g. |
| L* | 94 in. |
| Ae/At | 4·3 |
| Outside diameter | 12·5 in. |

*Fuel Pump:—*

| | |
|---|---|
| Speed | 14,000 r.p.m. |
| Delivery pressure | 650 p.s.i. |
| Specific speed | 325 |

*Oxygen Pump:—*

| | |
|---|---|
| Speed | 14,000 r.p.m. |
| Delivery pressure | 450 p.s.i. |
| Specific speed | 410 |

# CONFERENCE ON THE PHYSICS OF THE IONOSPHERE

*Cambridge, September* 6–9, 1954

By A. E. Slater, M.A., F.R.Met.S.

Twice as many delegates came to this gathering as attended the Oxford Conference on "Rocket Exploration of the Upper Atmosphere" a year earlier, in spite of the subject being more specialized. In fact, rockets were seldom mentioned this time, and when they did intrude, they were apt to disturb established theories.

Delegates came from 17 different countries, including Australia and Japan, but it was remarkable how many were working in countries other than their own. Thus Prof. Alexander came from Nigeria and Dr. Sen from Colorado, while Mr. Gnanalingam was in Cambridge; Prof. Rawer worked for the "Service de Prévision Ionosphérique Militaire" but had written a text-book in German which was published in Holland and is on sale at Heffer's bookshop in England; and the Rev. J. R. Koster was an American from the Catholic University of the Gold Coast, where everyone is in Holy Orders, whatever his job. There are more than 50 ionospheric research stations scattered over the world, their wide distribution being due to the fact that the ionosphere makes long-distance radio communication possible—and at times impossible.

Delegates were housed mostly in Corpus Christi College, conveniently next door to the Cavendish Laboratory where the conference was held. Dr. J. A. Ratcliffe, Director of Radio Research at the Cavendish, organized it most efficiently on behalf of the Physical Society. He kept everyone to a strict timetable—15 minutes per person per paper—with a contrivance showing coloured lights, starting with green, changing to yellow three minutes before time was up, and then to red, whereupon, it was explained, "the speaker stops." And, with one exception, the speaker always did. Dr. Hulburt, from America, asked if he might take a blue-print of this useful gadget home.

The ionosphere is the region from about 80 to 400 kms. (50 to 250 miles) where solar radiation splits off electrons from atoms and molecules, the remainder of each particle then becoming an ion. The behaviour of these electrically charged particles is so difficult to explain that, although many of the delegates had already spent a fortnight at two similar conferences at Amsterdam and Brussels, they were still unable to stop arguing about their pet subject at every opportunity; even at meal times it was impossible to get anyone to pass the bread, the salt, or even the water.

The greater part of the research effort goes into attempts to understand the irregularities which cause radio interference, and the variety in their behaviour and possible explanation is bewildering. Most of the probing work consists of sending up radio pulses into the ionosphere and analysing the reflections that come down; different wave-lengths are reflected at different levels. Sub-divisions of the ionosphere are designated by letters of the alphabet, but Dr. Ratcliffe was insistent that the term "region" should cover the whole height

range to which each letter applied, whereas the term "layer" should only be used for the levels of maximum ionization. He also insisted that "winds" should only mean movements of the main body of air, and "drifts" should be the name for motions of charged particles along electro-magnetic lines of force.

The D region, between 80 and 100 km., is the lowest one known; it appears sporadically and may encroach downwards into the region known variously as the ozonosphere, chemosphere, or upper stratosphere. Radio reflections from it have only been obtained in Cambridge and in Germany; elsewhere its presence is recognized by the way it causes fade-outs by absorbing radio waves intended for higher levels. S. Gnanalingam gave its thickness as 5 km. and said it forms over areas more than 1,000 km. wide, mainly in the winter months in medium-to high latitudes but at the equinoxes near the equator. W. Dieminger, of the Max Planck Institute at Lindau, said that he has got night-time echoes from the 90–95 km. level which he attributed to meteoric dust, giving a maximum at 6 a.m.; but this dust is not the cause of the D layer.

A Viking rocket ascent on May 7, 1954, which reached 219 km. (136 miles), was claimed by E. O. Hulburt (Naval Research Laboratory, Washington) to have proved quantitatively that the D region can be caused by solar radiation at a single wave-length known as the Lyman alpha line of hydrogen; the line showed against a continuous spectral background "of intensity appropriate to a solar temperature of less than 4,500° K." This should have upset any solar physicists with their 6,000°, but Dr. Donald Menzel, though listed as a delegate, was not there. From its effect in lowering the D layer, H. Friedman deduced that the intensity of the sun's radiation in the Lyman alpha wave-length must increase a thousand fold during solar flares. He added that it creates the D region by photo- ionization of nitrous oxide.

As an aside, it is of interest that all the nitrous oxide in the atmosphere (about 1 part in 20,000) can be explained as having been put there by the earth's vegetation, according to R. M. Goody in a recent paper to the Royal Meteorological Society. So, of course, can the oxygen, which is ionized at higher levels; so a dead earth would have a poor ionosphere, as well as no one to investigate it.

Prof. A. H. Waynick, of Pennsylvania State University, aptly summed up present knowledge about the D region as "surprisingly inadequate."

The aforementioned rocket ascent produced evidence that the higher ionospheric regions, E and F, could be quantitatively accounted for by solar X-rays, though ultra-violet could be a contributor to the highest region, the F. It also brought useful evidence of the composition of the ions at various levels, obtained with a mass spectrometer, which registers what atomic masses are present, though the reliability of the measurements seemed to be doubted by one delegate who expressed "unbounded admiration for the courage of anyone who would attempt" to interpret the resulting spectrograph.

The E region nearly dies out at night because the positively and negatively charged particles soon re-combine and no new ones are then being produced. But the F region continues all night because the air up there is so rarefied that the particles take much longer to find each other and re-combine. Ionospherists talk a lot about this "re-combination rate," especially when confronted with

unacceptable density data from rockets, which are apt to throw their calculations out of gear because the re-combination rate is so dependent on density of the air.

The E region, which was included in the first section of the Conference entitled "The Lowest Ionosphere," has its base at about 100 km. In addition to the usual radio echo from it, there are certain sporadic short echoes attributed to ionization in meteor trails; but G. Isted, of Marconi's Wireless Telegraph Co., claimed from recent experiments that most of these were due to ionization by upward discharges from thunderstorms, especially in the tropics, and that these discharges "maintained the E region at a high potential."

Auroras with a ray structure also occur at the E level and give scattered radio reflections which appear to be compounded of echoes from many short-lived ionization trails. B. Nichols, of Cornell University, has had the apparently original idea of examining auroras through high-power field glasses, and has found some auroral rays to "consist of a large number of fine streaks, each of which extends only part of the length of the ray and lasts only about a second." It was tempting, H. G. Booker said, to associate these streaks with the radio reflections.

The two last-mentioned items belonged to the second section of the Conference, under the heading: "Irregularities and Movements in the Ionosphere." It covered a vast number of observations in both the E and F layers, most of which boiled down into two main types. One is a sort of focusing of the radio echoes, generally believed to be caused by ripples on the under-surface of an ionospheric layer. But J. L. Pawsey, of Sydney University, thought the focusing might be done, not by reflection from the concave surface of a ripple, but by refraction through a lens-shaped aggregation of charged particles. Typical dimensions of such ripples in the F region were given as 50–400 km. in wave length and up to 5 km. in depth, with speeds of 100-300 m./sec. (220–670 m.p.h.); in the E region, 1–5 km. wave length, 40 m./sec. speed.

Moving concentrations of electrons account for the other main type of irregularity; ionospherists seem never to grow tired of studying them, having been at the job already for a quarter of a century without discovering their cause. They seem to move downwards, but is this because they really move horizontally with a front border tilted forwards, giving the impression of downward motion as the front passes over? Or does such an inclined front move downwards too? Is the tilt due to its travelling faster above than below, as found in Wales by W. J. G. Benyon? If so, why did a disturbance travel from Hobart to Brisbane at the same speed top and bottom, Dr. Martyn asked? And so on, almost interminably.

Dr. D. F. Martyn, F.R.S., from Canberra, the only other B.I.S. member at the Conference, put forward the "dynamo theory," of which he is the leading exponent. According to this, electrons carried along by winds in (probably) the E layer thereby set up a field in which other electrons in the F layer can move vertically, either up or down, this direction being at right angles to both the electric and the magnetic lines of force, which are at right angles to each other. This, he claims, should explain disturbances in the F region.

The third section of the Conference dealt with the $F_2$ region, the upper of the two layers into which the F splits in the daytime. It is believed to extend to

400 km., and is the highest region, apart from some suggestion of a G which the Conference ignored.

Radio echo-sounding, used to investigate the irregularities already mentioned, is only effective up to the level of maximum ionization density from which the wave-length in use is reflected, but not beyond. But the new science of radio astronomy has got over this difficulty. Just as the visual twinkling of stars gives information about atmospheric irregularities, which R. Fürth (Birkbeck College) said had a typical width of 30 cm. and speed of 15 m./sec., so the "twinkling" of radio stars in radio wave-lengths can show up "inhomogeneities" in the ionosphere, especially at the top. A. Maxwell (Jodrell Bank) gave a typical speed of 50–300 m./sec., increasing to 400 m./sec. in the auroral zone and, during gross geomagnetic disturbances, to 1,200 m./sec., which is about the speed of sound in the F region. Motion is towards the west till midnight, and to the east thereafter. The cause, he suggested, is turbulance from non-laminar flow, as the Reynolds Number at 400 km., for instance, is of the order of 300.

The rocket of last May just reached the base of the $F_2$ region, and by doing so gave rise to a discussion on a very highbrow level, which Dr. Martyn summed up by saying: "If the rocket values were correct, the $F_2$ wouldn't behave as it does, but would keep diffusing downwards."

As to the space above the inonosphere, a rather startling theory, or shall we say hypothesis, was put forward by J. W. Dungey of Pennsylvania State University. The Earth moves through ionized gas which is itself moving round the Sun. The magnetic field creates a cavity round the Earth, which the ionized gas cannot get into, and the Earth's motion relative to the gas sets up waves on the inner surface of this cavity. Could these waves, he suggested, induce disturbances in the ionosphere? What a phenomenon for an orbital satellite to investigate!

The fourth section of the Conference was: "The Mathematics of Wave Propagation through the Ionosphere." Since the mathematicians, it was explained, insist on talking a language which nobody else can understand, they were allotted a lecture room to themselves and told to go there and get on with it.

# CALCULATION OF STEP-ROCKETS

By M. Vertregt*

SUMMARY

A simple system of notations and ratios is proposed for the calculation of step-rockets. Three ratios are used, which are sufficient for basic calculations.

All ratios are defined in such a manner that their values are greater than one; the equations derived from these ratios are simple and symmetrical.

Some examples of calculations are given.

There is no uniform method available to denote the weights of the principal parts of a step-rocket and the ratios which are calculated from these weights.

American,[1] English[2] and German authors[3] use different systems, which makes their papers difficult to read, and renders it still more difficult to compare their results.

* *A paper presented at the 5th International Astronautical Congress at Innsbruck, 1954.*

The German authors have developed an elaborate system of notations and ratios; no less than eight different ratios are formulated. It is the opinion of the author that a simpler treatment would be adequate, and he proposes a system based on only four weights and three ratios, which are sufficient for the calculation of the basic figures of a step-rocket.

Fig. 1 gives a simplified scheme of a step-rocket, showing the notation of the principal parts.

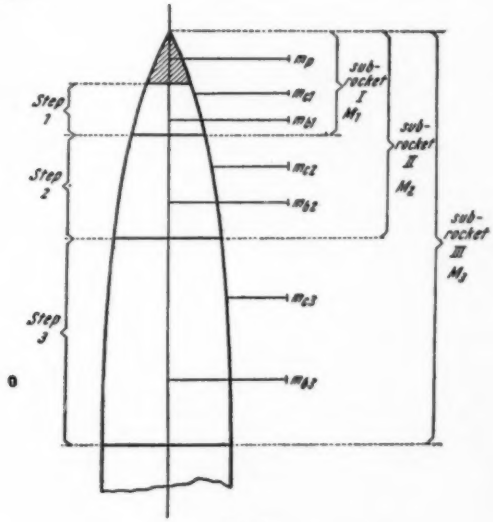


FIG. 1

A step rocket consists of: (*a*) steps, (*b*) sub-rockets.

A sub-rocket is a combination of steps which acts as a complete rocket during flight. In the sketch the steps are numbered by arabic numerals and the sub-rockets by roman numerals. This division of a step-rocket in steps and in sub-rockets is important; confusion may be caused by not clearly discriminating between these two.

Contrary to accepted custom the author has numbered the steps from top to bottom. As the calculation of a step-rocket starts from the payload in the top and then proceeds from the topmost step downward, it is rational to number the steps accordingly.

The four principal parts of the rocket are denominated as follows:

$m_p$ the *payload*. This is the *weight* of the *load* for which the rocket is built, and therefore the most important weight in the calculations. The payload may consist of instruments, or of men and instruments, *inclusive* of the structure necessary to support and protect these. In the calculations sub-rocket I is treated as the payload of sub-rocket II, sub-rocket II as the payload of sub-rocket III, etc. The payload does not belong to a step.

$m_c$ the *dry weight* of a step; i.e., the weight of the empty tanks, the motor, the pump-unit, the fuselage, the frame-work, the steering mechanism, etc.

$m_b$ the *weight* of the *propellants*, to which may be added the weight of the hydrogen peroxide for the pump-unit; in short, the weight of all chemicals which disappear during flight.

$M$ the *total weight* of a *sub-rocket*. $M_n$ is the total *weight* of a complete *step-rocket* of $n$ steps.

Indexes, indicating the steps or sub-rockets, are affixed to these notations; for instance: $m_{c2}$, $m_{b1}$, $M_3$, etc., i.e. dry weight of second step, propellant weight of first step, total weight of sub-rocket III, etc.

From the definitions given it follows that:

$$M_1 = m_p + m_{c1} + m_{b1} \quad .. \quad .. \quad .. \quad (1)$$

$$M_n = M_{n-1} + m_{cn} + m_{bn} \quad .. \quad .. \quad (2)$$

The ratios used are:

$p$ the *payload ratio*. This is the *weight* of a *sub-rocket*, divided by the *weight* of the *payload* belonging to that sub-rocket.

Thus:
$$p_1 = \frac{M_1}{m_p} \quad .. \quad .. \quad .. \quad .. \quad (3)$$

$$p_n = \frac{M_n}{M_{n-1}} \quad .. \quad .. \quad .. \quad .. \quad (4)$$

$P$ the *overall payload ratio* is the *total weight* of a *step-rocket*, divided by the *payload* of the *first step*.

Thus:
$$P = \frac{M_n}{m_p} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

Furthermore: $\frac{M_1}{m_p} \cdot \frac{M_2}{M_n} \cdot \ldots\ldots\ldots\ldots\ldots \frac{M_n}{M_{n-1}} = \frac{M_n}{m_p} = P$

Thus:
$$P = p_1 . p_2 \ldots p_n \quad .. \quad .. \quad .. \quad (6)$$

$P$ is the most important ratio of a step-rocket. For a practical project, $P$ must not exceed a reasonable value. What a "reasonable" value is, depends on economic and technical considerations, but the author agrees with Krause,[3] to put provisionally:

$$P < 500$$

$s$ the *structural ratio*. This is the *total weight* of a *step*, divided by the *dry weight*.

Thus:
$$s_1 = \frac{m_{c1} + m_{b1}}{m_{c1}} \quad .. \quad .. \quad .. \quad (7)$$

$$s_n = \frac{m_{cn} + m_{bn}}{m_{cn}} \quad .. \quad .. \quad .. \quad (8)$$

$r$ the *mass ratio*. This is the *weight* of a *sub-rocket before burning*, divided by the *weight* of that sub-rocket after *burning* of the propellant of the lowest step.

Thus:
$$r_1 = \frac{M_1}{M_1 - m_{b1}} \quad .. \quad .. \quad .. \quad .. \quad (9)$$

$$r_n = \frac{M_n}{M_n - m_{bn}} \quad .. \quad .. \quad .. \quad .. \quad (10)$$

The structural ratio $s$ could, by analogy, be called the mass ratio of a step, but it is better to avoid this confusing expression.

The mass ratio determines the ideal velocity which a rocket can attain in a gravitationless field and without air resistance, according to the equation:
$$V_i = c \ln r \quad .. \quad .. \quad .. \quad (11)$$

where $c$ is the velocity of the exhaust gases.

In the case of a step-rocket the ideal velocities of the sub-rockets may be added, so that the total ideal velocity of a step-rocket of $n$ steps is given by:
$$\Sigma V_i = c_1 \ln r_1 + c_2 \ln r_2 + \ldots c_n \ln r_n \quad .. \quad .. \quad (12)$$

When the $c$'s are equal for all steps:
$$\Sigma V_i = c \ln r_1 . r_2 \ldots r_n \quad .. \quad .. \quad .. \quad (13)$$

$R$ is the *overall mass ratio*.
$$R = r_1 . r_2 \ldots r_n \quad .. \quad .. \quad .. \quad (14)$$

Thus:
$$\Sigma V_i = c \ln R \quad .. \quad .. \quad .. \quad .. \quad (15)$$

And:
$$R = e^{\frac{\Sigma V_i}{c}} \quad .. \quad .. \quad .. \quad .. \quad (16)$$

when $c$ is equal for all steps.

The ratios $p$ and $s$ are defined in such a manner that their value is greater than one, in accordance with the universally used mass ratio. This too is in contrast with accepted practice, but the advantages of this method are first of all that ratios greater than one give a clearer picture of the actual circumstances than decimal fractions do, and secondly, they are easier to memorize. Furthermore the equations, derived from the ratios, are more symmetrical when all ratios are constructed in the same manner, thus, for instance, avoiding the use of negative powers.

The three ratios $p$, $s$ and $r$ are interrelated by the equation:
$$\frac{r-1}{r} = \frac{s-1}{s} . \frac{p-1}{p} \quad .. \quad .. \quad .. \quad (17)$$

From this it may be derived that:
$$s = r . \frac{p-1}{p-r} \quad .. \quad .. \quad .. \quad (18)$$

$$p = r . \frac{s-1}{s-r} \quad .. \quad .. \quad .. \quad (19)$$

$$r = \frac{p . s}{p + s - 1} \quad .. \quad .. \quad .. \quad .. \quad (20)$$

From these three equations for single step-rockets the equations for rockets with more steps can be derived.

Thus for a rocket of $n$ steps:

$$m_{cn} = m_p . R . \frac{r_n - 1}{r_n} \cdot \frac{s_1 - 1}{s_1 - r_1} \cdot \frac{s_2 - 1}{s_2 - r_2} \cdots \frac{1}{s_n - r_n} \quad .. \quad .. \quad (21)$$

$$m_{bn} = m_p . R . \frac{r_n - 1}{r_n} \cdot \frac{s_1 - 1}{s_1 - r_1} \cdot \frac{s_2 - 1}{s_2 - r_2} \cdots \frac{s_n - 1}{s_n - r_n} \quad .. \quad .. \quad (22)$$

$$M_n = m_p . R . \frac{s_1 - 1}{s_1 - r_1} \cdot \frac{s_2 - 1}{s_2 - r_2} \cdots \frac{s_n - 1}{s_n - r_n} \quad .. \quad .. \quad .. \quad (23)$$

Hence:

$$P = R . \frac{s_1 - 1}{s_1 - r_1} \cdot \frac{s_2 - 1}{s_2 - r_2} \cdots \frac{s_n - 1}{s_n - r_n} \quad .. \quad .. \quad .. \quad (24)$$

When the structural ratios $s$ and the mass ratios $r$ are equal for all steps/sub-rockets, we get the simple equations:

$$P = p^n \quad .. \quad .. \quad .. \quad .. \quad .. \quad (25)$$

$$R = r^n \quad .. \quad .. \quad .. \quad .. \quad .. \quad (26)$$

$$P = R\left(\frac{s-1}{s-R^{1/n}}\right)^n \quad .. \quad .. \quad .. \quad (27)$$

$$R = P\left(\frac{s}{P^{1/n} + s - 1}\right)^n \quad .. \quad .. \quad .. \quad (28)$$

With the aid of these equations other ratios can be easily constructed, for instance:

The total weight of the propellants of a step-rocket, divided by the total weight of the rocket:

$$\frac{M_{bn}}{M_n} = \frac{s-1}{s} \cdot \frac{P-1}{P} \quad .. \quad .. \quad .. \quad (29)$$

The total dry weight of a step-rocket, divided by the total weight of the rocket:

$$\frac{M_{cn}}{M_n} = \frac{1}{s} \cdot \frac{P-1}{P} \quad .. \quad .. \quad .. \quad .. \quad (30)$$

($s$ and $r$ equal for all steps/sub-rockets).

However, for basic calculations the first three ratios are sufficient.

In conclusion some simple calculations are given as examples:

*Example* 1. A single step-rocket of total weight of 500 tons has a payload of 1 ton. Thus: $P = 500$. The structural ratio: $s = 5$.

How much would a two-step-rocket weigh with the same ideal velocity, if the structural ratio remains unchanged?

$$m_c = \frac{M - m_p}{s} = \frac{500 - 1}{5} = 99{\cdot}8$$

$$r = \frac{M}{m_p + m_c} = \frac{500}{1 + 99{\cdot}8} = 4{\cdot}960$$

$$\frac{V_i}{c} = \ln r = 1{\cdot}6014$$

For the two-step-rocket: $$\frac{\Sigma V_i}{c} = \ln r^2 = 1{\cdot}6014$$

$$r = 2{\cdot}227$$

$$p = r.\frac{s-1}{s-r} = 3{\cdot}213$$

$$P = p^2 = \underline{10{\cdot}32}$$

which is about 1/50 of the weight of a single step-rocket.

*Example* 2. A four-step-rocket has the following characteristics:

$$\Sigma V_i = 9{\cdot}0 \text{ km./sec.}$$

(ideal velocity to reach circular velocity).

$$c = 2{\cdot}4 \text{ km./sec.}$$

$$s = 4{\cdot}7$$

(characteristics of the Viking).

$c$, $s$ and $r$ are equal for all steps.

What would be the total weight of such a rocket for a payload of 1 ton?

$$R = e^{\frac{9{\cdot}0}{2{\cdot}4}} = e^{3{\cdot}75} = 42{\cdot}5$$

$$P = R\left(\frac{s-1}{s-R^{1/n}}\right)^n = 42{\cdot}5\left(\frac{4{\cdot}7-1}{4{\cdot}7-42{\cdot}5^{1/4}}\right)^4 = 372.$$

Thus, such a rocket would weigh 372 tons, an acceptable figure.

*Example* 3. A lunar return trip with no landing on the Moon requires according to Clarke[4] a theoretical velocity of 22·4 km./sec.

How much would a ten-step-rocket weigh, having the same $s$ and $r$ as the preceding rocket and the same payload?

$$R = e^{\frac{22{\cdot}4}{2{\cdot}4}} = e^{9{\cdot}33} = 11\,270$$

$$P = 11\,270\left(\frac{4{\cdot}7-1}{4{\cdot}7-11\,270^{1/10}}\right)^{10} = 3{,}160{,}000.$$

Such a rocket would weigh 3,160,000 tons.

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(3) H. G. L. Krause. "Allgemeine Theorie der Stufenrakete," *Weltraumfahrt*, 1953, 52.
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WALDORF RECEPTION

In the foreground Mr. A. C. Clarke chats to Mrs. Patchett. Seated (facing camera) is Mrs. Smith talking to Mrs. Humphries, and to the right are Mr. R. A. Smith (Vice-Chairman of the Council) chatting with Mr. R. Cox Abel and Mr. H. E. Ross (back to camera). On the extreme right is Col. P. A. Campbell.

LONDON DINNER AT THE WALDORF HOTEL, OCTOBER 16, 1954

Left to right: Dr. L. R. Shepherd (standing), seated Mr. P. E. Cleator, Mrs. Cleator, Mrs. Shepherd, Mr. L. J. Carter, Mr. A. V. Cleaver, Miss H. Ziegler, Mr. A. C. Clarke, Dr. A. E. Slater (right, behind Mr. Clarke).

# 21ST ANNIVERSARY CELEBRATIONS

**October, 1954**

**London**

All readers of this note will be well aware that our Society celebrated the 21st anniversary of its founding last October. Very few of us knew it in the days of its extreme youth, but those who were already dedicated to the noble aim of space conquest before the war, remember a small oasis of enthusiasts surrounded by a desert of sceptics and scoffers and it was especially pleasant for those of us to join the large gathering of members and guests which assembled at the Waldorf Hotel on the 16th October to toast the emergence of the B.I.S. from adolescence into full maturity. The B.I.S. has now won recognition for itself as a fully responsible adult scientific organization whose aims are generally admitted to be capable of attainment in the forseeable future. Two decades ago it appeared most unlikely that "this highly improbable society," as our founder Mr. Cleator has described us, had such a secure future ahead of it, but anyone attending the London celebrations could hardly fail to sense the healthy enthusiasm of the present-day membership and to be convinced of the ultimate successful accomplishment of our great task. It seems only the day before yesterday that a small bar parlour was a rendezvous of sufficient size for those who wished to drink to the coming space age. To-day, not even the Waldorf could hold all our well-wishers and many late applicants for tickets had to be refused.

Before taking their places at the tables, diners had the opportunity of meeting the Guests of Honour, Professor Hermann Oberth and Mr. P. E. Cleator, and the members of the Council. A favoured few were even able to exchange courtesies with the Secretary as he passed through the assembly at a velocity only a trifle less than that necessary to achieve complete escape. Happily, this key official remained with us throughout the evening and, although his orbit was often highly eccentric and occasionally somewhat perturbed, there was never any doubt but that his programming was as near optimum as could be wished. The Society was also honoured to number amongst its guests the Secretaries of the Royal Astronomical Society and of the Royal Aeronautical Society. Eventually, the Chairman, Dr. L. R. Shepherd, was coaxed away from the camera with which he had been busy recording the occasion for posterity and the really serious business of the evening commenced. The souvenir menu described all these dishes in the approved French style, but, penetrating behind this disguise, diners were quick to recognize a pair of old favourites, sole and chicken fortified by the appropriate wines.

A loyal toast having been proposed by the Chairman and drunk by the entire assembly, congratulatory messages from other member societies of the International Astronautical Federation were read. A number of members of these societies were present in person, including Mr. K. Höie, a member of the Council of the Norwegian Interplanetary Society who now rose to propose a toast to our Society and its Founder, Mr. Cleator. Mr. Cleator welcomed the opportunity to deny in public the rumours that he had already travelled to the Moon and that he wrote under the pseudonym of "Arthur Clarke." It was particularly

WALDORF DINNER

Professor Oberth replies to a toast. Seated to his right are Dr. L. R. Shepherd (Chairman of the Council) and Mrs. Shepherd. To his left are Mr. A. C. Clarke and Mr. K. Hoie (Council Member of the Norsk Interplanetarisk Selskap).

WALDORF DINNER

Reading from left to right are: Miss H. Ziegler, Mr. E. Burgess (N.W. Branch Secretary), Mr. D. J. Cashmore (Member of the Council), Mr. J. C. Tysoe and Miss J. Müller.

WALDORF DINNER

From right are Mr. K. W. Gatland (Member of the Council), Mr. J. Houtman (representing the N.V.R.), Mr. D. F. Lawden (Member of the Council), Mrs. Lawden and Mrs. Gatland.

unfortunate for his publishers that the latter rumour had no basis in fact. Recalling the pre-war years, he remembered how the idea of space travel was then dismissed as hopelessly visionary by many men now eminent in scientific fields. The advent of the V2 had altered the whole climate of opinion and to-day we could confidently look forward to the 121st anniversary being celebrated on the Moon.

Mr. R. A. Smith, Vice-Chairman of the B.I.S., in proposing a toast to the guests, foresaw the day when some successor of his would be assigned the difficult task of welcoming other distinguished visitors from Venus and Mars to a truly interplanetary gathering. Professor Oberth said a few words in reply and apologised for his inability to speak English more fluently.

Mr. A. V. Cleaver, past Chairman of the B.I.S., proposed finally a toast to our main objective—the achievement of space flight! He reiterated his belief in the desirability and practicability of space travel and thought that it would have been achieved by the end of this century. In the meantime, we who awaited this event could enjoy the feeling of belonging to a very superior sort of club.

The speeches were followed by a film show, the chief item in which dealt with the testing and launching of the Viking rocket. It was not possible to screen the cartoon sequence from *Destination Moon* as had been planned, and instead lighter entertainment for the ladies was provided by two cartoons depicting life in the barnyard. The first of these cartoons was much improved by a defect in

MEETING FOR STUDENTS

A very junior spaceman examines critically a Midlands Branch model included in the display.

MEETING FOR STUDENTS

A general view of the meeting for students in the Grand Hall of Caxton Hall. (A similar meeting was held also in the York Hall of Caxton Hall at the same time in order not to disappoint the many hundreds of eager students wishing to attend.)

the sound apparatus which lowered the key signature by about four octaves. Unfortunately, after a few minutes our projectionists emerged the victors from combat with their infernal machine and the remainder of the reel had to be imbibed neat.

For the remainder of the evening members and guests were able to dance, take food and drink at the buffet or even indulge in space travel talk according to their preferences. At midnight the band packed up and went home, but not so all the diners. Many lingered on, chatting in groups around the tables, perhaps reluctant to put an end to a day so memorable in the annals of our Society. Eventually, however, the friends, old and new, dispersed and the B.I.S. entered upon its twenty-second year having established a small stake in the past but looking forward to playing the responsible role which will come its way in the future as the peoples of this planet enter the Space Age.

**Meetings of Students**

Earlier in the day, as part of the Society's 21st Anniversary Celebrations, the Council had decided on a special meeting for 5th and 6th form students and their teachers, from schools in the London area, to afford them an opportunity of hearing speakers and obtaining first-hand information on the subject of space flight.

Accordingly, a meeting was arranged for the afternoon of October 16, to be held in the Grand Hall of Caxton Hall (capacity 500) and a programme of five short talks and several films agreed upon.

Within a few weeks all available seats had been allotted, and the pressure of applications was so great that it was decided that, rather than disappoint so many people, a concurrent but independent series of lectures should be held in the York Hall (capacity 300). These seats were also all allotted within a very short time.

The arrangement of two concurrent series of lectures and film shows was obviously rather a tricky business, even though the times were slightly staggered but, in general, events proceeded smoothly in spite of occasional heart failure on the part of the helpers.

Attendance at both meetings was excellent, even though a current bus strike must have caused very great difficulty to many of the audience.

The Grand Hall meeting was under the Chairmanship of Dr. L. R. Shepherd, who gave a short talk and introduced the following speakers:—

(*a*) A. C. Clarke who spoke on "*Orbits.*"
(*b*) P. Moore on "*Planetary Conditions.*"
(*c*) J. Humphries on "*Fundamentals of Rocket Engineering.*"
(*d*) K. W. Gatland on "*Space Stations and Orbital Vehicles.*"

The York Hall meeting was under the Chairmanship of Mr. D. Hurden, who opened the proceedings with a talk on basic principles of rocket engineering.

Other speakers were Mr. Armstrong, who described some medical aspects of space flight, Mr. G. V. E. Thompson, who spoke on the uses of a space-station, and Mr. K. W. Gatland who described some recent rocket research.

Both series of lectures concluded with a number of interesting films, which included the *"Viking," Ascent of Monkeys and Mice in an Aerobee rocket,"* etc., and both before and after the programme students were able to examine a small exhibition which had been arranged. Notable among these exhibits were a Sprite rocket (kindly loaned by the De Havilland Aircraft Co., Ltd.), an excellent series of paintings by Mr. D. Hardy and a number of models loaned by the Midlands Branch. Also on display was a selection of photographs on rocket development and a display of books arranged by H. K. Lewis & Co., Ltd.

During the meeting a number of Fellows were available near the exhibits to answer questions from the eager youngsters and to provide general assistance in ensuring that the arrangements proceeded according to plan.

**Birmingham**

The Birmingham Branch celebrated the anniversary at the Crown Inn, Broad Street, Birmingham on the evening of October 23. About 60 members and guests attended, Dr. L. R. Shepherd and Mr. D. F. Lawden representing the Council. The Branch were also very pleased to welcome Mr. and Mrs. Cleator and Dr. and Mrs. Hilton.

Whilst the company was assembling, early arrivals availed themselves of the opportunity of meeting the distinguished guests and Council members. Dinner being served, conversation became somewhat muted as all applied themselves to the tasks of consuming the excellent dishes placed before them and of studying the souvenir menu which a local artist had decorated with a cartoon depicting a rocket of unorthodox design about to take off, with a crew to match.

Glasses having been replenished, the Chairman of the Midland Branch, Mr. R. B. Beard, proposed a toast to the Queen and this being drunk the assembly gave their attention to the after dinner speakers. Dr. Shepherd was first called upon to propose a toast to the Society and its Founder. In doing so, Dr. Shepherd reviewed the history of the B.I.S. since its formation in 1933 and compared the comparative affluence of our present position with the economic difficulties with which the pre-war Society had to contend. He paid tribute to the Secretary, Mr. Carter, whose business acumen was so largely responsible for our present sound financial status. Mr. Davison, a member of the Branch Committee, then rose to welcome the guests. He saw in Dr. Shepherd not only a very welcome guest but also a symbol of atomic power which would one day, no doubt, drive our space ships. Dr. Hilton was an expert in the field of high speed aerodynamics and we would welcome his assistance in solving the problems associated with the return of a ship to Earth.

In reply Mr. Cleator expressed his thanks and Dr. Hilton permitted himself to make one or two speculations. For example, are the small Martian moons artificial satellites set up by an earlier Martian civilization? He also confessed that having calculated that the optimal shape for the return step of a three stage rocket was a disc, he began to adopt a very much more favourable attitude towards the frequent reports of flying saucers.

The tables were now cleared away so that the company was able to break up into groups to converse agreeably over a flagon of ale until mine host called for "last orders."

Midlands Branch Dinner on October 23, 1954

**Bristol**

About 70 to 80 members and guests enjoyed a very fine dinner arranged by the Provisional Western Branch in the magnificent Grand Hotel, Bristol.

The Guest of Honour was Dr. J. Black, from Bristol University, while Mr. P. Moore and Mr. L. J. Carter (Secretary) represented the Council.

The guests first foregathered in a reception room to imbibe wines and effect introductions, and later wandered into the fine banqueting room where a most enjoyable meal had been arranged.

The Branch Chairman, Mr. J. Corbett, welcomed the members and guests of honour, and after the toast had been drunk to the Queen, Mr. Black rose to propose a toast to the Society. His speech contained a great deal of interesting information about the early history of the Royal Aeronautical Society and was well received. Replying to the toast Mr. Carter, with some feeling on the subject, described a few of the various nails which had been driven into his coffin since he became Secretary and proceeded in a very humorous speech to give first-hand information on such things as organizing film shows, editing the Journal, dealing with crazy people, and such-like.

This was suitably capped by Mr. P. Moore who explained that he hadn't much to say as he hadn't had sufficient time to write out his impromptu speech.

After the dinner speeches, those present enjoyed a short film show on various (silent) rocket and other newsreels. The commentaries were given by Mr. Carter, but since the films had not been screened before, the commentaries followed close behind the actual pictures at a sort of supersonic gallop.

During the dinner, the large model of the von Braun rocket constructed by members of the Branch was on display in the centre of the room.

## B.I.S. 21st ANNIVERSARY

## MESSAGES OF CONGRATULATION

The following are extracts from messages of congratulation received by the Society:

*"We do not know at this moment whether we will be able to send our representative; if it is not possible we will be present spiritually to the said celebrations, acknowledging the exceptional merits the B.I.S. got for the advancement of Astronautics."*—PROFESSOR A. EULA, Associazione Italiana Razzi.

*"Both personally and as Vice-President of the I.A.F. I wish you all the luck in the future, and thanks for what the B.I.S. has meant for the idea of space-travel in the past 21 years. Give my greetings to everybody."*—E. BUCH-ANDERSEN, Dansk Interplanetarisk Selskab.

*"We always keep our great respect for your activities. I sincerely hope that your Society will make progress and success."*—MITSUO HARADA, Japanese Astronautical Society.

*"Very cordial congratulations on British Interplanetary majority from little Dutch sister. Best wishes for future achievements."*—N.V.R., Holland.

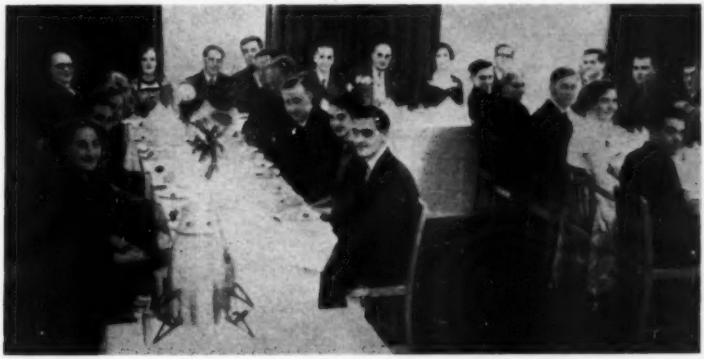
*"Please accept our warmest congratulations to this honorary day of the famous B.I.S.!"*—FRIEDRICH HECHT, President, Österreichische Gesellschaft für Weltraumforschung.

*"On the occasion of the 21st anniversary of the British Interplanetary Society, may we extend to you the heartiest congratulations and best wishes of the officers and membership of the Royal Astronomical Society of Canada."*—DOROTHY C. WILLIAMSON, R.A.S. of Canada. Assistant Secretary.

*"We also wish to express our congratulations on the 21st anniversary of your Society, and say that we hope that time will enhance still further the honoured position that you hold in world astronautics."*—P. CARLSON, South African Interplanetary Society.

*"On the occasion of the coming of age of the British Interplanetary Society, the S.I.S. wishes to extend the warmest congratulations and hopes for continued progress."*—AKE HJERTSTRAND (Chairman), KARL-HUGO BETZFELDT (Secretary), Svenska Interplanetariska Sällskapet.

*"Your Society can be really proud of its achievements in the past period and optimistically look into the future. With numerous membership, a respected publication, well-attended lectures, high quality of scientific work and high reputation. May your work and co-operation in the International Astronautical Federation help the promotion of the ideas and aims of astronautics towards the real conquest of space by our science."*—KOSTA SIVCEV, President, Yugoslav Astronautical Society.



North-West Branch Dinner, October 9, 1954

**Manchester**

The celebrations of the North-Western Branch took the form of a Dinner held at the New Millgate Hotel, Long Millgate, Manchester 4, when about 30 members and guests attended.

The Guests of Honour were Mr. and Mrs. P. E. Cleator and Mr. H. L. Burney, Principal of the College of Adult Education Manchester. In addition, the Chairman of the Society, Dr. L. R. Shepherd and three other Council members, Messrs. R. A. Smith, W. Neat and D. J. Cashmore, visited Manchester for the occasion. A surprise visitor was Mr. L. J. Johnson, first Secretary of the Society, who arrived with Mr. Weedall one of the original Liverpool members.

The toast to H.M. The Queen was proposed by the Chairman, and Dr. Shepherd then gave a résumé of the history of the Society and proposed a toast to the Guests.

Mr. P. E. Cleator responded on behalf of the guests and he amused everyone with a witty speech outlining some of the events during the Society's early days.

Finally Mr. C. A. Cross, Branch Chairman, expressed his pleasure on behalf of the Branch that so many visitors had travelled long distances to be present, and then gave a short speech for the Branch and its Committee.

After the dinner, members and guests spent their time exchanging reminiscences, examing the model of the Smith Lunar Landing Rocket which had been constructed by Mr. Cross and periodically posing for photographs by Dr. Shepherd and Mr. Fallows.

**Leeds**

About 30 members and guests attended the dinner given by the Yorkshire Branch at Jacomelli's Restaurant, Leeds, on October 30.

The Council was represented by Mr. J. Humphries and Mr. L. J. Carter (Secretary), while Mr. E. Burgess represented the North-West Branch.

After the toast to the Queen had been drunk, Mr. L. S. Strickson proposed a toast to the Society, to which Mr. Carter replied with a short speech describing

North-West Branch Dinner on October 9, 1954

some of the early history of our Society and a few of the problems which we had to overcome to establish the Society on a sound basis.

The toast to the branches was proposed by Mr. Burgess. Mr. Humphries replied on behalf of the Council, stressing the importance of strong and virile branches in the development of the Society and making some comparisons of the position of space flight on our 21st Anniversary with the position of aeronautics on the 21st Anniversary of the Royal Aeronautical Society. One of the papers mentioned as being read during the 21st Anniversary year of the Royal Aeronautical Society was apparently "On blowing up a balloon"—a rather belated source of reference for those "volunteers" at the London meeting who earlier in the month had to undertake the unenviable task of blowing up hundreds of balloons at the Waldorf.

A number of photographs were on display and after the dinner, the members and guests spent some time in examining these and engaging in conversation on subjects of mutual interest.

**Acknowledgements**

The Council wishes to acknowledge with grateful thanks the help and enthusiasm shown by Branch Secretaries, Branch Committees, and many Fellows in the London area who rose nobly to the occasion and provided invaluable support in making these celebrations a success.

Acknowledgements are also due to the De Havilland Aircraft Co., Ltd., for the loan of the "Sprite" rocket, to D. Hardy for many paintings, to the Midlands Branch for the loan of models which were displayed both at the meeting for Students and the subsequent dinner, and to R.P.D. Westcott for the loan of equipment.

Further thanks are due to Mr. E. Burgess, Mr. G. V. E. Thompson, and Miss H. Ziegler, all of whom aged about ten years coping with the Society's new and infernal projector for most of the day.

# BASIC PRINCIPLES OF ASTRONAUTICS

By L. R. Shepherd, Ph.D., B.Sc., A.Inst.P.

(This is the first of a series of articles which have been written as a result of requests from members who wish to have a reasonable scientific account of the principles and problems of space flight. The purpose of the series is entirely educational and it is intended primarily for the scientifically-trained newcomer.

The present article gives a fairly elementary account of the principles of rocket flight in gravitational fields leading up to an assessment of the magnitude of the task of flying to the Moon and the lesser task of setting up orbital rockets. Later papers will outline the engineering aspects of the rocket and introduce some of the basic ideas of interplanetary orbits.—Editor.)

## Elementary Principles of Rocket Flight

A rocket in its simplest form consists of a fuselage containing a motor, tanks full of the propellants and a payload. The propellants are pumped into the motor where they undergo a vigorous chemical reaction generating gas at a high temperature and pressure. This gas, produced in the combustion chamber of the rocket motor, expands through a nozzle and emerges from the rear of the rocket as a high velocity jet. The rocket recoils from the ejected gas in the same way as a gun recoils from its projectile, for the internal pressure of the gas, which forces it out of the nozzle, at the same time pushes the rocket in the opposite direction.

In contrast to other vehicles, a rocket does not maintain a continuous propulsive effort. Instead, it operates in a single burst of powered flight during which the highest possible speed is built up and, thereafter, it coasts in an orbit or ballistic trajectory. An interplanetary rocket might require several bursts of power, to cover various operations of take-off and landing, but the same general principle of concentrating the propulsive effort into the least possible time, would still be followed, since this would give the optimum performance.

The factors governing the performance of a rocket can be demonstrated by an examination of a few simple mathematical relations which apply during the period of powered flight. It is fairly easily shown that the thrust of the rocket motor, i.e. the force of recoil from the gas leaving the nozzle, is equal in magnitude to the product of the velocity of ejection of the gas (exhaust velocity) and the rate of discharge of material in the jet (mass of gas ejected per second). Denoting these two quantities by $c$ and $dm/dt$ respectively, then the thrust $F$ is given by the expression:

$$F = -c.\frac{dm}{dt}$$

The negative sign indicates that $F$ and $c$ are oppositely directed. If a rocket were operating in space in a region of zero gravitational field then at any instant the acceleration of the rocket would be proportional to the thrust of the motor in accordance with the well-known law: Force = Mass × Acceleration. Thus the rocket has an equation of motion;

$$-c.\frac{dm}{dt} = m.\frac{dv}{dt}$$

where $dv/dt$ is the acceleration of the rocket and $m$ its mass at a given instant. Of course, since the rocket is throwing out matter at a rate $dm/dt$ its mass $m$ is changing at a rate $-dm/dt$. If the rocket starts from rest with an initial mass $m_0$ and after burning all its propellants has a mass $m_1$, then, provided that the motion was in a straight line, the final velocity $v$ is easily derived from the equation of motion and found to be:

$$v = -c.\log_e(m_0/m_1)$$

The ratio $R = m_0/m_1$ is called the *mass ratio* of the rocket and is the useful quantity expressing the amount of propellants carried by the vehicle. This velocity attained by the rocket in space, in the absence of gravity, is the real measure of its performance, which for the want of an accepted term, will be called, hereafter, the *characteristic velocity* of the rocket. A V2 rocket has a mass ratio of approximately 3 and a characteristic velocity just under 3 km./sec. The characteristic velocities required for astronautical purposes are many times greater than this figure, as will be demonstrated in the ensuing discussions.

In the general case, a rocket will be moving through a gravitational field and also, for restricted periods, through an atmosphere. The discussion of the effect of air resistance on the motion of a rocket will be postponed until later, attention being confined for the present to the predominating gravitational effects. The action of gravity during the period of powered flight of a rocket results in a loss of velocity, because not all of the thrust of the motor is available for the acceleration of the rocket, some being required to support the weight, or some fraction of the weight of the vehicle. In the case of a rocket starting from rest and climbing vertically through a constant gravitational field of intensity $g$, for example, it is easily seen that the maximum velocity of the rocket falls short of the characteristic velocity by an amount $gt$, where $t$ is the time taken for the rocket to complete its powered flight. Actually, it is not the maximum speed, but the total energy given to the rocket, which is important. This total energy includes, not only the kinetic energy $\frac{1}{2}mv^2$, but also the potential energy $mgh$, $h$ being the height of the vehicle in the assumed constant field. Supposing that the rocket in the present example climbs with a constant acceleration $a$, during the period of powered flight, then the total energy $W$ given to it would be:

$$W = \tfrac{1}{2}\,mv^2 + mgh = \tfrac{1}{2}\,mv_e^2\left(\frac{a}{a+g}\right)$$

where $v_e$ is the characteristic velocity. It is seen from this result that the greater the acceleration of the rocket, the greater the energy imparted to it. For this reason, one would attempt generally to use the maximum available thrust of the rocket motor rather than control the thrust to give a constant acceleration. Once the motor of the rocket has cut out, the vehicle coasts with a constant total energy, any increase in potential energy being balanced by a decrease in kinetic energy. Only the operation of the motor or the resistance of an atmosphere or collision with another body can change the total energy.

Astronautics is not a matter of rockets moving in constant gravitational fields, of course, but rather of motion in the "inverse-square-law" fields of the earth and other planets. Many of the problems of astronautics can be simplified,

TABLE I

| | $r_0$ km. | $g_0$ m./sec.$^2$ | $\sqrt{2g_0r_0}$ km./sec. |
|---|---|---|---|
| Earth .. .. | 6,400 | 9·81 | 11·2 |
| Moon .. .. | 1,740 | 1·62 | 2·4 |
| Mars .. .. | 3,400 | 3·77 | 5·1 |
| Venus .. .. | 6,200 | 8·52 | 10·3 |

without undue loss of accuracy, by considering only one attracting body at a time. Thus, in assessing the performance required of a rocket going to the moon, one can obtain quite adequate precision by considering that the vehicle is either exclusively influenced by the earth or exclusively influenced by the moon, depending on its position. This would not do in an actual flight to the moon, needless to say!

The acceleration of a body towards an attracting planet can be conveniently referred to the acceleration $g_0$ at the surface (radius $r_0$) i.e., at a distance $r$ from the planet the acceleration (or gravitational field intensity) is simply:

$$g = g_0r^2_0/r^2$$

The potential energy of a body of mass $m$ in this field is equal to $-mgr$ or $-mg_0r^2_0/r$. The reason for the negative sign is that the potential energy at infinity is taken to be zero and since potential energy of a body must obviously increase as the distance of the body from the attracting centre increases then at all distances less than "infinity" the potential energy must be negative. The total energy of the body at distance $r$, then, is:

$$W = \tfrac{1}{2}\, mv^2 - mg_0r^2_0/r$$

A body at rest at the surface of the planet has a potential energy $-mg_0r_0$ and if it is projected from that surface with a velocity $v_0$, then its total energy is $\frac{1}{2}\, mv^2_0 - mg_0r_0$. Supposing that the body is projected vertically, then it will climb until its speed is reduced to zero so that it has only potential energy $-mgr^2_0/r$. The maximum radius $r$ which the body reaches is determined, then, by the simple equation:

$$-mg_0r^2_0/r = \tfrac{1}{2}mv^2_0 - mg_0r_0$$

It is easily seen that, if $v^2_0$ is equal to $2g_0r_0$, then the rocket may attain an infinite radius, in other words it may escape completely from the planet. For this reason we refer to the velocity $\sqrt{2g_0r_0}$ as the escape velocity. Note that if a body be projected away from the surface at this speed, the direction of projection is not important insofar as its ability to escape is concerned, but, if the velocity of projection is less than the escape speed, then the maximum radius reached will depend upon the angle of projection, since that will determine the shape of the orbit of the body and how much of its kinetic energy may be converted into potential energy. In the following table, values of $r_0$, $g_0$, and escape velocity at the surface of the Earth, Moon, Mars and Venus are listed.

If the speed of projection exceeds the escape velocity, the body has a residual speed at infinity which is very sensitive to the projection velocity. This can

easily be seen from the energy equation which, in this case, we write in the form:

$$\tfrac{1}{2}mv^2_\infty = \tfrac{1}{2}mv^2_0 - mg_0r_0$$

since the residual energy is kinetic. Thus, if $v_0$ is 12·2 km./sec., the residual velocity at infinity would be 4·8 km./sec. In other words, an extra kilometer per second at take off is worth nearly five times as much at infinity. It is readily appreciated from this observation that the transit time of a rocket going to the moon would depend very strongly on the initial velocity. Furthermore, a small error in projection velocity would necessitate a very serious correction to the speed of the rocket if it were left until the vehicle had reached a great distance.

It will be observed that a body projected from the surface of a planet at escape velocity has zero total energy. If a body starts from rest at infinity and falls on to the surface of a planet, then it will have zero total energy at all times during the fall and consequently must arrive at the surface at escape velocity. If a rocket is designed to escape from the earth, its characteristic velocity must of course exceed the escape velocity. It was indicated earlier that a rocket moving in a constant field, with a constant vertical acceleration, lost energy in the ratio $a/(a + g)$. This loss is higher than that which would be encountered in the inverse square field of a planet as one can easily verify by a simple analysis of the motion during powered flight in such a field. However, for accelerations greater than $2g_0$ the difference is not worth considering and we may determine the required characteristic velocity from the escape speed, in these circumstances, by means of the simple expression:

$$v^2_c = v^2_0\left(\frac{a + g_0}{a}\right)$$

Thus, given a constant acceleration $a = 3g_0$, a rocket escaping from the earth would require a characteristic velocity of 12·9 km./sec.

**The Requirements of a Lunar Rocket**

As a first exercise, the requirements of a rocket travelling from the surface of the Earth to that of the Moon and back will be considered, no account being taken of the Earth's atmosphere. Four separate operations are involved, viz.:

(1) Acceleration from the surface of the Earth until the total energy is zero.

(2) Arrival at the Moon at zero total energy. This means crashing to the surface at the lunar escape velocity unless some braking action is applied. On an airless world this involves using the rocket motor as a brake to reduce the speed to near zero.

(3) Take off from the Moon accelerating up to zero total energy.

(4) Arrival at the Earth and use of rocket braking to reduce speed to zero, i.e., to reduce the total energy of the rocket from zero to $-mg_0r_0$.

Strictly speaking the energy of the rocket need not be raised to zero, since it is never at infinite distance from the two worlds. However, the difference between the real state of affairs and that assumed above is small.

Operations 1 and 4 are strictly equivalent if the acceleration used for taking off from the Earth is equal in magnitude to the retardation used in landing.

Thus at $3g_o$, a characteristic velocity of 12·9 km./sec. would be required for both cases. Similarly the lunar operations (2) and (3) are equivalent. In the lunar case $g_o$ is only one sixth of the terrestrial value and we may assume that the loss from the finite acceleration would be negligible. Thus, both the landing and take off at the Moon would require characteristic velocities equal to the lunar escape speed, i.e., 2·4 km./sec. The characteristic velocity of a rocket capable of carrying out, in succession, all four of the above operations is equal, obviously to the sum of the characteristic velocities demanded for the separate operations. In the case of a rocket capable of $3g_o$ constant acceleration, i.e., 29·4 meters/second/second, this sum amounts to 30·6 km./sec. This is more than ten times as great as the characteristic velocity of a V2 rocket.

The rocket in this example would just succeed in reaching the Moon and returning with long transit times in excess of 100 hours. An extra kilometer per second at take off would reduce the transit time to about 20 hours, but the speed of arrival at the Moon would be increased to 5·4 km./sec. as a result. If the corresponding procedure were adopted on the return flight, then the required characteristic velocity would be raised to 38·6 km./sec.

**Aerodynamic Aspects of Space Flight**

The effect of the Earth's atmosphere manifests itself, in astronautics, as a possible obstacle on the outward flights, but a definite asset on return flights. This is because the retarding action of the air resistance increases the required characteristic velocity for leaving the Earth, but reduces it in the case of a rocket returning to the Earth. Of course, the important property of the atmosphere, in so far as the rocket is concerned, is its density and the way in which the density varies with altitude. At sea level the normal density $\rho_o$ is about 0·0012 gm./cm.$^3$ The following table gives the ratio of densities at various heights to that at sea level.

TABLE 2

| *Height. Km.* | $\rho/\rho_o$ |
|---|---|
| 0 | 1 |
| 10 | 0·35 |
| 20 | 0·078 |
| 30 | 0·157 |
| 40 | 0·0035 |
| 50 | 0·00097 |
| 60 | 0·00029 |
| 80 | 0·000018 |
| 100 | 0·00000072 |

The actual height to which the atmosphere extends is indeterminate, but at heights greater than 100 km. it is already in the nature of a vacuum according to laboratory standards and above 200 km. it is certainly a better vacuum than any produced by man.

The resistance of the air to any body moving through it at low velocities is proportional to the dynamic pressure of the air i.e., the pressure $\frac{1}{2}\rho v^2$ generated by the motion of the body. At high velocities the drag increases more rapidly than the square of the velocity of the body, but it is customary, nevertheless, to write the expression for the resistance $F$ to a body with velocity $v$ in the form:

$$F = \tfrac{1}{2} C_d \rho v^2 A$$

where $A$ is the cross sectional area of the body at right angles to the motion and $C_d$ is the so-called drag coefficient. $C_d$ varies with velocity very rapidly as the

speed of sound is approached, but at speeds substantially in excess of that of sound it falls off as $(M^2-1)^{-\frac{1}{2}}$ where $M$ is the Mach No.

At sea level it would be quite impossible to fly through the air at velocities approaching those required in astronautical ventures. However, if a rocket starts off at a reasonably low acceleration and climbs steeply through the atmosphere, then the rapidly falling density $\rho$ soon counteracts the increasing quantity $C_d v^2$ so that $F$ increases at first, reaches a maximum value and then falls away to a very small value. The overall effect on the rocket as it emerges from the appreciable atmosphere can be represented by a loss of velocity given by the expression:

$$v_a = \int_o^T \frac{F}{m} \cdot dt$$

where $m$ is the mass of the rocket at some instant $t$ and the upper limit $T$ of the integration is any time interval greater than that required to cross the appreciable atmosphere. If a rocket requires a characteristic velocity $v_e'$ to escape from an airless Earth, then escape from the Earth with atmospheric resistance will require a characteristic velocity $v_e = v_e' + v_a$.

The value of $v_a$ for a vertically ascending V2 rocket is about $\frac{1}{2}$ km./sec., a value which could be regarded as typical of any large vehicle with a similar ratio of weight to cross section. On this basis a rocket escaping with a constant acceleration $3\,g_o$ during powered flight would need a characteristic velocity of 13·4 km./sec. instead of the value 12·9 km./sec. calculated in the absence of air resistance.

The influence of the atmosphere on a returning rocket is a subject of considerable speculation at the present time. It is thought that the air might be used to absorb completely the energy of a rocket entering it in an orbit with a speed in the range 8 to 11 km./sec. (the former value corresponding to a nearly circular orbit and the latter to a parabolic orbit). Of course the rocket would need to remain at a great altitude (*circa* 80 km.) while its velocity was so high and for this reason it would enter the air at a tangent and might be provided with wings to prevent it from spiralling in to the surface too rapidly. The main problem encountered would be that of frictional heating. The rocket would be moving head on into an air stream having a relative speed $v$ and as this air became stagnated in the boundary layer around the skin of the vehicle it would be raised in temperature by an amount $v^2/2C_p$, where $C_p$ is the specific heat at constant pressure of the air. This is actually a somewhat hypothetical figure that assumes the air is instantaneously brought to rest in an adiabatic manner. In practice, it would represent an upper limit to the boundary layer temperature. However, at the velocities with which the rocket would enter the air, i.e., $v = 8$ to 11 km./sec., the stagnation temperatures would run into tens of thousands of degrees Kelvin. Provided that the vehicle be kept at a sufficient altitude while such a state of affairs persists, the heat transfer to the skin of the rocket could be limited to a manageable level. Even so the skin temperatures in the hottest regions (near the nose of the rocket and the leading edges of the wings) might be about 1,000° C. or more, so that substantial refrigeration would be demanded in a manned vehicle.

The successful utilization of atmospheric braking would result in very useful reductions in the characteristic velocities of space vehicles. Even so, it is doubtful whether a rocket intended to land upon and return from the surface of the Moon could be based on a characteristic velocity of less than about 25 km./sec. allowing some margin for error.

**The Satellite Vehicle**

The first and easiest objective in astronautics is the projection of a rocket into a circular orbit. The speed of a rocket in an orbit of radius $r$ is given by the equation;

$$u^2 = gr = g_0 r^2_0 / r$$

where $g$ is the gravitational intensity at the orbit. The total energy of a body in this orbit is $-mg_0 r^2_0/2r$, whence it follows that a rocket projected from the surface of the planet into the orbit must be given an amount of energy $mg_0 r_0 - mg_0 r^2_0/2r$. Neglecting air and gravity losses, it can be deduced from this that the necessary characteristic velocity $v_c$ is given by:

$$v^2_c = 2u^2_0\left(1 - \frac{r_0}{2r}\right)$$

where $u^2_0 = g_0 r_0$ i.e., $u_0$ is the circular orbital velocity at the surface. It will be seen that the escape velocity is exactly $\sqrt{2}$ times the circular orbital velocity, so that for any orbit around the earth the characteristic velocity, neglecting the losses is given by;

$$v^2_c = (11{\cdot}3)^2\left(1 - \frac{r_0}{2r}\right) \text{ km.}^2/\text{sec}^2.$$

For example, in the case of a rocket circling the Earth at 1,000 km. above the surface ($r = 7{,}400$ km.) the characteristic velocity is 8·45 km./sec.

Calculation of the "gravity loss" is more complicated than for the vertical ascent, since both the acceleration and the angle of ascent must be taken into account. In all probability the initial part of the ascent would be nearly vertical in order to minimize the air loss, the track turning over gradually after the denser region of the atmosphere had been crossed. Some advantage could be gained by choosing an equatorial orbit going in the easterly direction, since the peripheral velocity at the equator (0·46 km./sec.) due to the Earth's rotation would then be added on to the tangential velocity produced by the rocket's motors. Taking all things into consideration the characteristic velocity of a vehicle designed to go into an orbit at a height of about 1,000 km. would be about 10 km. per second.

**Limitations on Characteristic Velocities**

Since the characteristic velocity of a rocket is directly proportional to the exhaust velocity of the motor, it is obviously advantageous to utilize as high a value of this as possible, provided that it is not done at the expense of mass ratio. The factors governing the exhaust speed will be discussed in detail in a later paper in this series. However, it would seem that with presently available

chemical propellants the maximum exhaust velocities would lie in the range 3 to 4 km./sec. With such low exhaust velocities, it would be practically impossible to build even the satellite rocket, discussed in the last section, using simple single stage construction. Multistage construction, in which a small rocket forms the payload of a larger rocket and the two together form the payload of a still larger rocket and so on, would be essential in order to obtain the lowest characteristic velocities required for astronautical purposes. Detailed consideration of multistage rockets is given in the paper by Vertregt (see pages 20—25). Some of the main features of the multistage construction are worth mentioning here, however.

As a rough rule it may be said that if a characteristic velocity $v_c$ can be obtained, for a given propellant mixture, in a single stage rocket, then in a rocket having $n$ stages, the same propellants and similar structural factors a characteristic velocity of $nv_c$ would be obtainable. Secondly, if in the single stage vehicle a fraction $1/p$ of the all-up weight is useful payload, then in the $n$-stage rocket the fractional payload is $1/p^n$.

These rules are approximate in so far as the structural problems of multistage vehicles are hardly likely to be the same as those for single stage vehicles and the structural factors obtained in individual stages of the former may not be the same as those obtained in the latter. The first rule suggests that there is no serious limitation on the characteristic velocity even if the exhaust velocity is limited. The second, however, indicates where the limitation lies. Thus, it would be reasonable, within the limitations set by existing possible exhaust speeds, to construct a single stage vehicle having $v_c = 4$ km./sec. and $p = 6$. A three stage vehicle, on the same basis, would have $v_c = 12$ km./sec. and $p^3 = 216$, i.e., a take-off weight 216 times as great as the useful payload. This would be reasonable as an engineering possibility, though not very economical. However, if we wanted a characteristic velocity of 24 km./sec., then the ratio of take-off mass to payload would be $p^6$ or almost 50,000!

The inevitable conclusion is that with existing propellants the projection of a vehicle into a circular orbit around the Earth is a real possibility, but the lunar vehicle with direct take-off from Earth, whose requirements were discussed in an earlier section, is not a feasible proposition.

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ARS Journals required by Fellow. Details of issues available and prices to Box 12, BIS, 12 Bessborough Gardens, London, S.W.1.

**21st ANNIVERSARY SOUVENIR POSTCARDS**

To mark the Society's 21st Anniversary, a special set of rocket postcards have been issued, size 4¼ in. by 5½ in. and are available at 3s. per set, post free.

They comprise the following:—

(*a*) "Viking" No. 9.
(*b*) Experimental "Hermes" rocket missile.
(*c*) "Viking" being fired at White Sands.
(*d*) WAC-Corporal and V2 booster rocket.
(*e*) "Viking" in firing position.
(*f*) WAC-Corporal and launching tower.

# NINTH ANNUAL GENERAL MEETING

(i) *Chairman's Speech*

About seventy members attended the Ninth Annual General Meeting, held in the Kent Room of Caxton Hall, on December 4, 1954, when Dr. L. R. Shepherd opened the proceedings by giving a short review of the past year's activities.

Dr. Shepherd said we had come a long way since the Society was first founded by Phil Cleator in Liverpool in October, 1933. Last year alone the Society held 41 General Meetings, and during the current year the number would increase to about 50—all in addition to the substantial number of outside lectures undertaken by interested Fellows, which probably totalled now about 200 each year. In fact they were so many that it was impossible to keep track of them, though further additions to the ranks of volunteers from qualified Fellows would always be welcomed.

"The past year," Dr. Shepherd continued, "was not a spectacular year, but it had seen a general improvement in our position. However, we have still a great deal of ground to cover in the attainment of our more immediate objectives, and I urge all of our members with technical qualifications and with something to say in the field of astronautics, to take up their pens and get to work." Dr. Shepherd added that we are always interested in receiving for consideration papers and articles for the *Journal*, ideas generally and offers for papers to be read at meetings, both in London and at the branches.

(ii) *Accounts to September* 30, 1954

After the Chairman's Speech, a proposal was made by Mr. R. A. Smith that the audited Balance Sheet and Accounts for the year to September 30, 1954, be approved. This was seconded by Dr. J. A. Moyse and carried unanimously.

(iii) *Council* 1954–55

The Chairman then explained that our normal practice was for the result of voting on nominations for the Council to be announced as the next item on the Agenda, but owing to circumstances outside our control, it had not been possible to issue the voting papers in good time.

As it was obviously undesirable to conduct such an election in a matter of a few days, particularly as we had many hundreds of members overseas who could not possibly vote in time, he proposed that this matter be adjourned until February 5, 1955, and announced to the meeting on that date.

This proposal was seconded by Mr. C. Fleisher, put to the meeting, and carried unanimously.

(iv) 1955 *Annual General Meeting*

The Secretary reported that the continued growth of the Society made it a matter of considerable difficulty to prepare the accounts, voting papers, *Annual Report*, etc., in time for the Annual General Meeting each year, and

that the Council had approved a special circular to members explaining how it was proposed to effect a change to enable a few extra months to become available for the completion of this work.

The proposed additional Annual General Meeting, which was to be held on May 14, 1955, would be largely a formality to comply with legal requirements, and the next Accounts for the year to September 30, 1955, would then be considered at an Annual General Meeting held in April or May, 1956, instead of December, 1955—the extra few months giving more elbow-room to enable the necessary preliminaries to be carried out.

(v) *The Journal*

After the main business had been dealt with, a general discussion took place on the Society's affairs.

A number of speakers referred to the question as to whether the Society should issue two Journals, as it was suggested that the existence of a purely technical Journal would carry much more weight in technical circles than our present hybrid *Journal*. Mr. E. Hope-Jones thought that a disadvantage of having a purely technical Journal would be that no one would understand much of it, while Miss Winick opposed the idea on the grounds that even technical readers are interested in the "background" information contained in the more general parts of our present *Journal*. Mr. A. V. Cleaver felt that eventually we should need to have both types of Journal, the only question being *when*.

The Secretary drew attention to a number of formidable editorial and administrative difficulties involved in such a change at the present time, and stated that it would only be of advantage if it could lead to an increase in the extent of our published material, but a simple division of our present publication was merely a way of spending several hundred pounds for no net increase and could destroy the regularity of publication if the material available was disjointed in size.

Mr. R. A. Smith advanced the suggestion that the same result might be achieved by issuing an annual or semi-annual publication containing reprints of all technical papers which could be made available to all interested members.

(vi) *Informal Meetings*

Several members made a plea for some informal meetings, and general support was found for the idea that these be held during the summer months, when the Society's main lecture programme had ended. The Chairman promised that this matter would be noted for consideration by the Council.

(vii) *Technical Study Groups*

A few members supported the idea of forming Technical Study Groups, but the Chairman drew attention to the Society's previous experiences in this direction and pointed out the many failures which had resulted in the past.

Mr. Cleaver said that it was not possible to impose obligations upon people; such groups depended entirely upon the creation of spontaneous interest in

suitably qualified people with ideas and enthusiasm who would carry out such plans. In the past they had either not been forthcoming or had been too busy to undertake these tasks. In cases where enthusiasm *did* exist, our experience had shown that the member concerned would carry out his work whether such a group existed or not.

The Chairman suggested that perhaps the first step should be made at the informal meetings where members could get to know each other and get some idea of the measure of support for future activities in this direction.

(viii) *Film Show*

Following the conclusion of the business session, the meeting adjourned and became informal, during which a number of silent, newsreel, etc. films were shown, aided and abetted in most cases with various commentaries, comments and asides by the Secretary.

(*a*) The first film showed the Cosmic Radiation research undertaken by the U.S. Navy in 1953 aboard the U.S.S. "Staten Island." These involved the ascent of balloon-borne rockets during the summer to test cosmic radiation and the pressure, temperature and density of the atmosphere in Arctic regions.

In the film a 55-ft. Skyhook plastic balloon was shown being filled and ascending with a small rocket (with instruments) attached. The rocket was usually lifted to about 70,000 ft. or higher before being automatically fired—rocket No. 6 reaching a height of 60 miles.

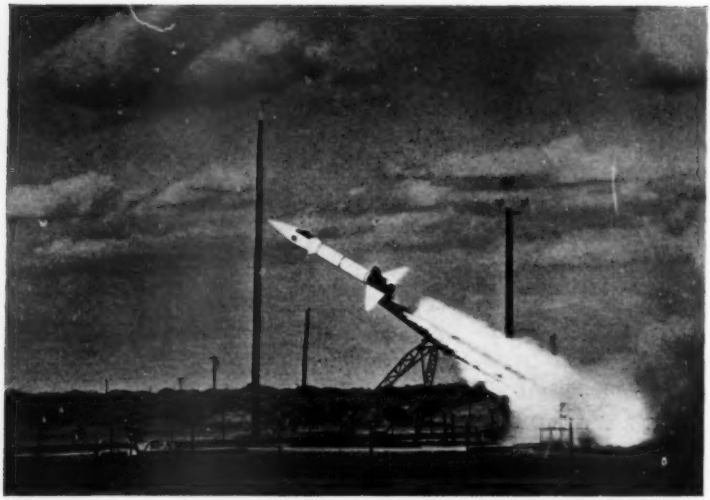
(*b*) The second film showed the U.S. Army's guided missile NIKE—named after the Greek Goddess of Victory and followed with a series of shots of earlier U.S. guided missiles.

(*c*) The third short film showed three rocket launchings—i.e., Viking No. 7 (which reached a height of 135 miles), Viking No. 10 (it was No. 11—the sister rocket of No. 10—which reached the new altitude record for single stage rockets, i.e., 158 miles, on May 24, 1954) and finally the famous V2/WAC Corporal launching.

(*d*) A little light relief was then afforded by a fine colour film taken of Zurich and its environs by Mr. A. C. Clarke during the Congress there in 1953, which showed many of the delegates taking part enjoying a period of well-earned relaxation.

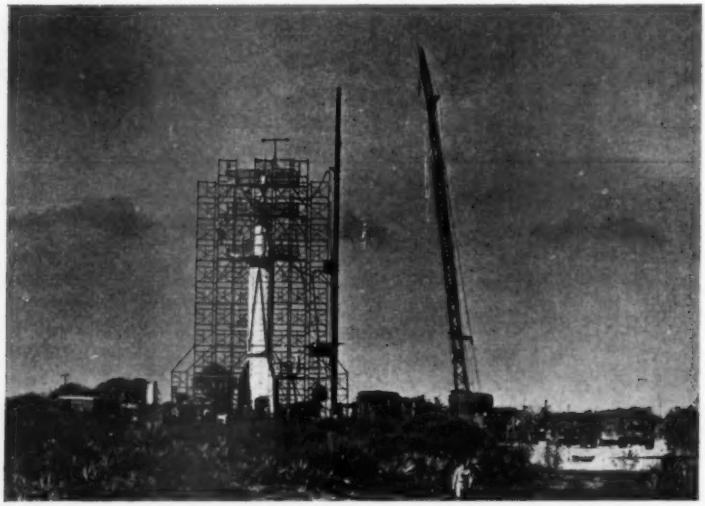
(*e*) The show concluded with two 8-mm. films taken by Mr. E. Burgess. The first contributed a most interesting historical record of the Paris, London and Stuttgart Congresses, the last including a number of shots of the rocket exhibition put on at the Landesgewerbemuseum.

The second 8-mm. film and the last of the show, was concerned with the recent 21st Anniversary Celebrations Dinner in London. It began with some shots of the students meeting earlier in the day in Caxton Hall in which some of the B.I.S. helpers appear, and then moved to the reception in the Palm Court of the Waldorf Hotel where guests are arriving. It showed the presentation of bouquets to Mrs. Cleator and Mrs. Shepherd, the arrival of Professor Oberth, and concluded with shots of the after-dinner speakers engaged in proposing and replying to the various toasts.



"Honest John"

A free-flight U.S. artillery rocket shown taking off from a test-type launcher at White Sands Proving Ground.



V2/WAC Corporal

The first firing of the V–2 Bumper Rocket (with a WAC Corporal mounted atop its nose) at Long Range Proving Ground Division, Cocoa, Fla., on July 12, 1950.

# NOTES AND NEWS

### Nominations for Council 1955–56

Enclosed with this Journal is a special circular to members explaining why the 1955 Annual General Meeting is being held on May 14, 1955, commencing at 6 p.m. at the York Hall of Caxton Hall, S.W.1.

In accordance with the provisions of Article 15 of the Society's Constitution one-third (i.e. *four*) Members of the Council (Messrs. J. Foley, K. W. Gatland, P. Moore and G. V. E. Thompson) will retire from office at that meeting.

Nominations are invited from members for election to the Council for next session.

Signed nominations should be forwarded to the Secretary as soon as possible, and in any event not later than April 2, 1955.

If the number of nominations exceeds the number of vacancies, voting papers will be prepared and forwarded to all members for completion and return before the date of meeting.

### Bankers Order for Payment of Subscription

The attention of members having bank accounts is drawn to the advantages of remitting annual subscriptions by using the Society's Bankers Order Form.

If this is completed and sent to the Banker concerned, subscriptions are paid automatically each year on the due date, which saves much trouble to the member concerned and materially helps the Society at a very busy time.

### Short Paper Evening

The 1954–55 London Lecture Programme includes a "Short Paper Evening," on May 14, 1955, and an invitation is extended to all members to submit short papers to be considered for presentation at this meeting.

It is important that each paper does not take longer than 10 minutes to read, and will be followed by 10 minutes discussion.

Members interested are asked to notify the B.I.S. Secretary of the title of their paper, a synopsis of its contents, and mention any special treatment or other points of interest, in order that the final programme can be arranged.

### Change in Lecture Programme

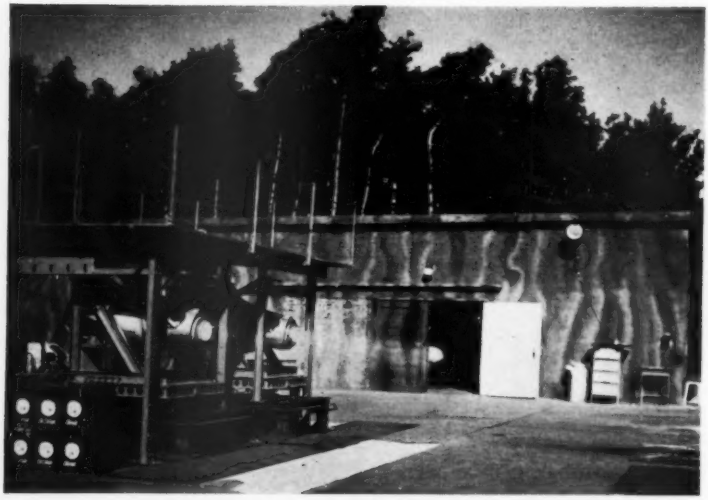
The "Short Paper Evening" arranged for the Leeds Meeting on January 22,, 1955 (at 3 p.m.) has been deleted and a Lecture by D. Hurden, B.A., Grad.I.Mech.E., substituted.

Mr. Hurden's paper will be "The Development of the 'Snarler' Rocket Motor," and give an account of some of the problems encountered in the development of this engine and the methods used to overcome them.

### Lecture Posters

A number of posters advertising the Society's London lectures are now available, and members who could use copies for display purposes are invited to write to the B.I.S. Secretary.

Peenemünde's test stand No. 1, where first tests with A-4 rocket motors were made. Built in 1937, this test stand was main motor facility for A-4 programme through January 1945. Baltic Sea in rear.



Two synchronized JATO units being tested on Peenemünde's test stand 4. 1941/42.

**1955 Annual Subscriptions**

The 1955 Annual Subscriptions fell due on January 1 and members are asked to remit as soon as possible.

The rates payable are as follows:—
Fellowship £2 12s. 6d. ($7.50): Membership £1 11s. 6d. ($4.50): Members under the age of 21 years £1 1s. 0d. ($3.00).

Those members having bank accounts would find it of great convenience to complete and send to their bank the Society's special Banker's Order form, as this would ensure that future subscriptions are paid automatically on the due date. This arrangement also benefits the Society considerably, as it leads to a substantial saving in time and expense.

Members who are able to do so may wish to consider the question of compounding future annual subscriptions by payment of a single lump sum, in accordance with the scale approved by the Council, details of which will be forwarded on request.

**Films Available for Hire**

(*a*) It is possible to obtain a black and white 16 mm. print of the film "Destination Moon" on hire from Davis Sound Film Equipments, 63 King Street, Maidenhead. The rental of the film for one exhibition is 70s., and the running time is 91 minutes.

(*b*) It is understood from Mr. Hackett, Fairey Aviation Co., Ltd., Weapon Division, Heston Aerodrome, Hounslow, Middlesex, that a film is available entitled "Bi-Fuel High Altitude Angle Launch Project." The film is in colour, with sound, and runs for 11 minutes.

**From the World's Press**

At last a use has been found for the rocket-driven sleds and railcars which some of the early rocket experimenters delighted in attempting to develop during the 1930's. They have not finally appeared as a means of passenger transportation but instead are used as vehicles for aero-medical research. Recently an American Air Force surgeon, Lt.-Col. John P. Stapp, became the fastest man on earth by riding in a rocket propelled sled along a railway-type track laid out in the New Mexico desert. A speed of 421 m.p.h.—18 m.p.h. faster than John Cobb travelled at Utah in 1947—was attained. The sled was then decelerated by scoops dipping into a water trough between the rails, and the reactions of the human guinea pig were registered by movie cameras and appropriate instruments. A maximum deceleration of 22 *g*'s was employed, and the U.S. Air Force is reported to have stated officially that these rocket sleds will be used at a speed of 800 m.p.h.

* * * *

Rocket power has also been applied to helicopters. During July a number of press reports were published concerning a one-man rocket-powered helicopter. Tiny rocket motors mounted on the tops of the rotor blades use hydrogen peroxide as a propellant.

* * * *

*The New York Journal of Commerce* for July, 1954, states that the Standard Oil Co. of Indiana has signed contracts with the U.S. Air Force to build and operate a plant for the pilot production of new types of solid propellants. The aim is to develop low cost propellants from petroleum sources.

* * * *

Some details of the "Rascal" were reported in the *Daily Telegraph* for April 27, 1954. After having been released from the bomb-bay of a B–36 or B–50 bomber at a distance of up to 100 miles from the target, the pilotless aircraft travels at Mach 1·5 powered by a turbo-jet engine. Control is by means of directions incorporated in the missile's electronic "memory" and the final approach to the target is corrected by controls from the mother aircraft which observes the progress of the missile by radar. During the summer, too, announcements were made that certain U.S. artillery missiles, i.e., "Honest John" and "Corporal" were being sent to Europe. "Honest John" is an unguided rocket weapon directed by a mobile launcher and capable of delivering an atomic warhead at a range of about 25 miles. "Corporal" is a much larger vehicle and is a guided long-range rocket, launched vertically and having a range comparable with the V2. Some of these missiles are to be made available to Commonwealth Forces for training purposes.

* * * *

From Australia have come reports—for example in *The Times* of June 7, 1954—that experiments will soon be started for research within the upper atmosphere. Dr. D. F. Martyn announced at a meeting in Canberra that "rockoon" type rockets would be launched from high-flying jet planes in order to complete a comparatively inexpensive series of observations of upper atmospheric conditions. Canberra bombers were to be used for this purpose at Woomera. The *Adelaide Advertiser of* June 19, 1954 quoted Dr. Martyn as having said that the instrumented earth satellite vehicle will be a natural sequence of rocket research at Woomera. It was not clear from this report whether Dr. Martyn had continued by saying that instrumented rockets with stable platforms similar to sunseekers, or that artificial satellites would be developed within the next ten to fifteen years. It is probable that he was referring to the former.

* * * *

An idea of the rapid growth of the British guided missile industry was given by Mr. Duncan Sandys, the Minister of Supply, when he opened Ferranti's new £1,000,000 research laboratory at Manchester during the summer. The *Manchester News Chronicle*, of June 26, 1954, stated that Mr. Sandys had said that over 100 firms are engaged in the manufacture of rockets, and that there are almost as many highly-skilled technicians employed on guided missiles as there are in the whole of our air-frame industry. This is encouraging news, for in all this work we are seeing the foundations of the engineering "know-how" for space flight being acquired. Unless some radically new form of atomic propulsion is discovered it will be this work in the field of the guided missile which will give us the knowledge of how to build space vehicles.

Described by the press as an imitation space-ship, a non-flying sealed cabin has been acquired by the United States Air Force. The information was released during August and reports stated that the cabin would be used mainly to test human reactions to cramped conditions and to recycled atmospheres. It will help to determine if the various factors affecting human well-being can be balanced artificially and how the minute traces of toxic substances which can build up in a recycled atmosphere may be eliminated.

* * * *

*The Observer*, of April 25, 1954 reported success in some experiments with suspended animation which had been carried out by the National Institute for Medical Research. Rats had been forced into conditions resembling those of hibernation. First they were made to breathe air rich in carbon-dioxide and short of oxygen. They were then placed in containers surrounded by ice and the body temperature thereby reduced to the freezing point of water. The tissues were then able to survive with negligible amounts of oxygen so that respiration and heart beats slowed and stopped. To all outward appearances the animals were dead. After remaining in this condition for an hour the heart was restarted by the application of gentle heat on the chest and artificial respiration was given. The animals returned to what appears to be a normal life. In this respect, Prof. Oberth made a statement to the press during August that suspended animation was one possible solution for achieving interstellar travel.

* * * *

"Scarborough may sell its spaceship"—*The Yorkshire Post* of July 17, 1954. There is no truth in the rumour that two dimunitive men in tight fitting garments of woven steel visited the Council chamber the other week to enquire of the price!

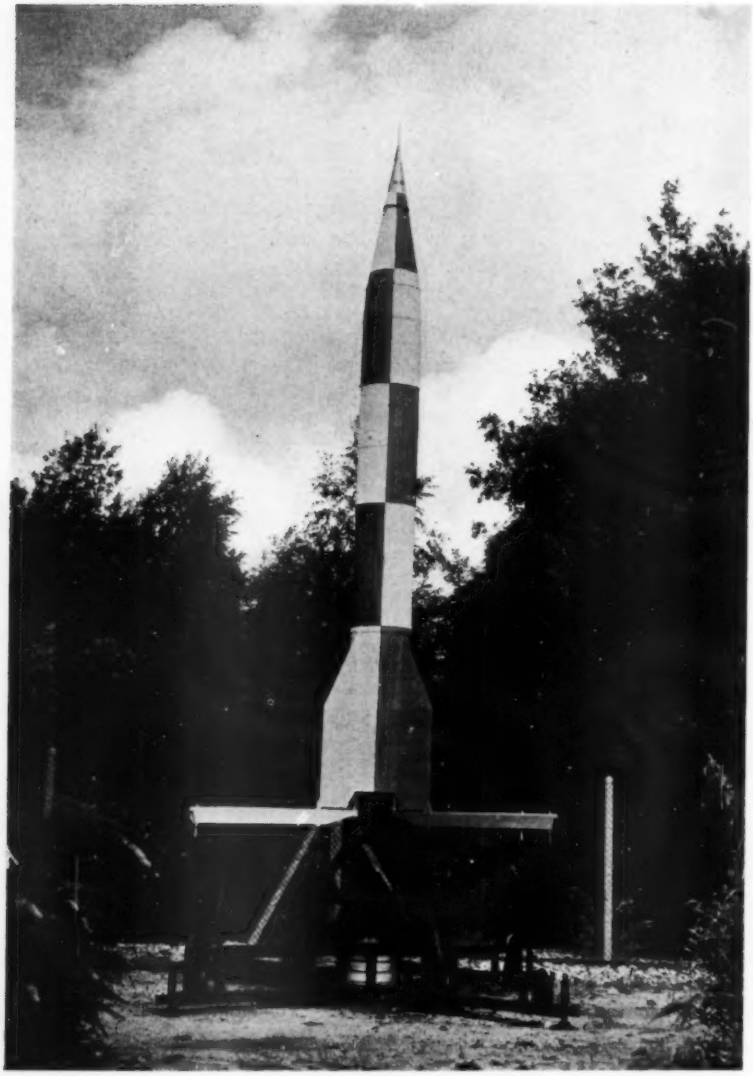
## DATA SHEETS

By Kenneth W. Gatland

This new series is intended to summarize, in a convenient form, the essential data on a wide variety of rockets, rocket powered aircraft and guided missiles. Later, it may be possible to include other items of interest, e.g., rocket motors, centrifuges, wind tunnels, etc.; in each case references will be given for further reading.

In future issues it is hoped to include four subjects, making 24 in each year. Needless to say, security considerations make it impossible in every case to include a full summary; however, additional information that comes to hand after a particular data sheet has appeared will be given in later issues, when the recipient can amend his sheets accordingly.

In view of the fact that members may like to keep the data sheets in a separate file, arrangements have been made to supply reprints (at a cost of 2s. 6d. per annum). Application for these may be made to the B.I.S. Secretary at any time, but the reprints will be dispatched in a single batch at the end of each year.



Veronique.

**A–4 (Germany).**

(*a*) Role: Surface-to-surface.
(*b*) Date: 1942.
(*c*) Length: 46 ft.
(*d*) Diameter, max: 5 ft. 6 in.
(*e*) Launching weight: 28,500 lb.
(*f*) Propellant weight: 19,750 lb.
(*g*) Payload weight: (Amatol filling 1,650 lb.) 2,150 lb.
(*h*) Thrust: 60,000 lb × 60 to 70 secs.
(*i*) Velocity, max: 5,200 ft./sec.
(*j*) Propellant: alcohol/liquid oxygen.
(*k*) Feed system: hydrogen peroxide turbo-pump.
(*l*) Range: 180 miles (average) 220 miles (max.).
(*m*) Altitude (at 45 deg. elevation): 60 miles.

Vertical take-off stabilized by gyro-controlled exhaust vanes; gyro made to precess and so turn rocket from vertical path through angle of 44 deg. in 52 secs. Flight time—launch to impact—approx. 5 mins. (over 190 miles). Control of velocity, by integrating-accelerometer, used to limit dispersion in range. Adapted for high-altitude research in U.S.A., has ascended 114 miles; as booster stage of 2-step rocket with WAC-Corporal, established max. altitude of 242 miles (max. velocity, 7,335 ft./sec.), Feb. 1949.

REFERENCES

(1) "*A critical review of German Long-Range Rocket Development*," by W. G. A. Perring, *Journal of the Royal Aeronautical Society*, July, 1946.
(2) "*V–2*," by Walter Dornberger, Hurst and Blackett, 1954.

**VERONIQUE (France)** Laboratoire de Recherches Ballistique et Aerodynamiques.

(*a*) Role: Surface launched, research.
(*b*) Date: 1950.
(*c*) Length: 19·7 ft.
(*d*) Diameter, max: 1·8 ft.
(*e*) Launching weight: 2,172 lb.
(*f*) Propellant weight: 1,323 lb.
(*g*) Payload weight: 123 lb. (instruments).
(*h*) Thrust: 8,820 lb. × 35 sec.
(*i*) Velocity, max: 4,500 ft./sec.
(*j*) Propellant: Nitric-acid/gas-oil.
(*k*) Feed system: gas-pressure.
(*l*) Altitude: max. estimated: 410,000 ft.

Launching is made from a simple platform, four cables unwinding from a drum (fixed to the launching table) being employed to obtain a stable ascent path. Outriggers provided at the base of the four fins serve as attachment points for the cables. The cables unwind at a uniform rate and maintain the rocket's stability while it is moving too slowly for the relative air-flow to have effect on the fins. The four outriggers, with the cables attached, are jettisoned from the rocket by explosive bolts controlled by a clockwork timer. Nose cone is separated from the rocket by explosive bolts shortly before reaching summit altitude, recovery being assisted by a drouge device. In tests Veronique has ascended 40 miles.

REFERENCES

(1) "*Development of the Guided-Missile*" (2nd edition, 1954), by K. W. Gatland, Iliffe and Sons, Ltd., pp. 184–5.
(2) *J.B.I.S.*, July, 1954, p. 230.

# ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles where given in the May, 1950 issue of the *Journal* and subsequent addenda have appeared to date.

In future, a list of these abbreviations will be included in the Annual Index, the first appearing in the index for volume 13 which is to be published shortly.

## AERODYNAMICS

(1) **The effect of mass transfer on the compressible turbulent boundary-layer skin friction and heat transfer.** W. H. Dorrance and F. J. Dore. *J. Aero. Sci.*, **21**, 404–410 (*June*, 1954). Theoretical study of the case where mass is injected into or withdrawn from a high-speed, turbulent, compressible boundary layer. (10 *refs.*)

(2) **Aerodynamic principles.** E. A. Bonney. *Aero. Dig.*, **69** (1), 61-62, 64 (*July*, 1954). Refers especially to missile problems.

## ASTRONAUTICS

(3) **Droppable stages may boost rockets to earth-circling orbits.** C. T. Aubrey. *Soc. Automot. Engrs. J.*, **60** (9), 18-23 (*Sept.*, 1952). Performance of step-rockets and general review of problems of space-flight.

(4) **The Third International Astronautical Congress.** A. Eula. *Aerotecnica*, **32**, 362-369 (*Dec.*, 1952) (*In Italian*). Review of Congress and abstracts of papers.

(5) **Interplanetary travel.** R. Sankaranayanan. *J. Madras Inst. Tech.*, **1**, 267-277 (1953). General review of the engineering and physiological problems.

(6) **A realistic approach to space flight.** E. Burgess. *Aircraft*, 30 (*Oct.*, 1953). General review and proposals for atomic rockets.

(7) **On the vertical climb of a rocket.** I. Sinra. *J. Japan. Soc. Aero. Eng.*, 48 (*March*, 1954). Performance under decreasing gravitational force. Considers both constant acceleration and constant thrust with charts of propellant requirements for escape.

(8) **The Fifth Astronautical Congress at Innsbruck.** G. Partel. *Alata*, **10** (8), 33-34, 37 (*Aug.*, 1954) (*In Italian*). Résumé of the business meetings and technical papers

(9) **The two new terrestrial moons and American astronautical policy.** W. Proell. *J. Space Flight*, **6** (9), 1-5 (*Oct.*, 1954). The possible uses of the newly discovered satellites at 640 and 960 km. altitudes as interplanetary bases. (9 *refs.*)

## ASTRONOMY

See also abs. no. 9.

(10) **Interplanetary gas.** E. J. Öpik. *Z. Astrophys.*, **35**, 43-60 (1954) (*In Germau*). Discussion of recent interpretation of the polarized component of zodiacal light as being due to scattering by free electrons. Large-scale magnetic fields must be assumed to account for certain phenomena or alternatively there may not be any appreciable amounts of interplanetary gas and the polarization may then be due to reflection from solid particles.

(11) **The origin of meteorites.** S. F. Singer. *Sci. Amer.*, **191** (5), 36-41 (*Nov.*, 1954). The use of helium content determination to determine the age of meteorites. The helium is formed by the action of cosmic rays in space.

## ATMOSPHERE

(12) **Day sky brightness measured by rocket-borne photometers.** H. A. Miley, E. H. Cullington and J. F. Bedinger. *Trans. Amer. Geophys. Un.*, **34**, 680 (*Oct.*, 1953).

(13) **Rocket-borne photometer measures sky light.** A. Corman and J. F. Bedinger. *Electronics*, **27** (9), 151-153 (*Sept.*, 1954). Description of instruments installed in Aerobee to determine the intensity and spectral characteristics of the light of the day sky to altitudes exceeding 70 miles. (1 *ref.*)

## BIOLOGY AND MEDICINE

(14) **Observations on the penetration of a heavy primary through tissue.** H. Yagoda and H. B. Smith. *J. Aviation Medicine*, **25**, 46-49, 66 (*Feb.*, 1954). Data obtained from a record from a Skyhook balloon at 95,000 ft. (10 *refs.*)

(15) **Experiments with animals and human subjects under sub- and zero-gravity conditions during the dive and parabolic flight.** H. J. A. von Beckh. *J. Aviation Medicine*, **25,** 235-241 (*June*, 1954). Tests with turtles and humans show marked disorientation during zero-g conditions (16 *refs.*)

## CHEMISTRY

See also abs. nos. 50 and 51.

(16) **Current hydrogen peroxide.** *Chem. Engng.*, 304-307 (*Aug.*, 1954). Flowsheet of hydrogen peroxide production by oxidation of ammonium bisulphate solution to persulphate, and hydrolysis to the peroxide.

## PHYSICS

See also abs. nos. 12, 13 and 14.

(17) **Determination of flame temperatures from 2000° to 3000° K. by microwave absorption.** P. W. Kuhns. *NACA Tech. Note No.* 3254, 48 pp. (*July*, 1954). Outlines procedure for obtaining flame temperatures from the attenuation of microwaves by temperature-induced free electrons. (16 *refs.*)

(18) **Determination of combustion temperatures by optical methods.** A. Moutet. *Rev. Opt.*, **33,** 313-338 (*July*, 1954) (*In French*). Review of methods, the line reversal method being discussed in detail. An apparatus based on this principle specially designed for rocket motors is described; this is capable of giving readings up to a rate of 4,500 per second.

## PROJECTILES

(19) **Push-button era is approaching.** D. A. Anderton. *Aviation Wk.*, **56** (8), 53-54, 57-58, 62 (*Feb.* 25, 1952). General review of post-war developments and future possibilities.

(20) **Rocket model does work of wind tunnel.** G. L. Christian. *Aviation Wk.*, **56** (23), 21-22 (*June* 9, 1952). Description of work carried out by Bendix Aviation Corp.

(21) **Long range missile testing.** *Air Univ. Quart. Rev.*, 29 (*Fall*, 1953). Survey of USAF development and research programme.

(22) **A guide to high-altitude rocket design.** *Aviation Wk.*, **59** (26), 28-31 (*Dec.* 28, 1953). Design problems of Viking.

(23) **U.S. unveils defensive missile system.** *Aviation Wk.*, **59** (26), 13-14 (*Dec.* 28, 1953). Description of Nike.

(24) **Missile directory.** *Aero Dig.*, **69** (1), 31-36 (*July*, 1954). Details and photos of Lark, Plover, Viking, Bumper, Hermes, Nike, Corporal, Terrier, Honest John, Bomarc, Matador, Regulus, Firebird and Sparrow.

(25) **Missile equipment.** *Aero Dig.*, **69** (1), 110, 112, 114, 116-118, 120, 122, 124, 126-136, 132-135, 138-140, 142, 144 (*July*, 1954). Descriptions of various commercially available missile accessories.

(26) **Nike.** *Aero Dig.*, **69** (1), 25-27 (*July*, 1954). Illustrated description.

(27) **Statement of the problem.** W. W. Bender. *Aero Dig.*, **69** (1), 22-24 (*July*, 1954). Discussion of problems of missile guidance.

(28) **Role of the electronic computer.** J. F. Donan. *Aero Dig.*, **69** (1), 76, 78 (*July*, 1954). Application of computers to missile data reduction.

(29) **Plastics future.** M. H. Gold. *Aero Dig.*, **69** (1), 106, 108-109 (*July*, 1954). Use of plastics in rocket combustion chambers and other missile components.

(30) **Attaining stability and control.** M. M. Munk. *Aero Dig.*, **69** (1), 69-70, 72, 74 (*July*, 1954). Reviews missile problems.

(31) **Electromagnetic problem.** S. S. Oleesky. *Aero Dig.*, **69** (1), 80, 82, 84 (*July*, 1954). Survey of materials problems connected with radome manufacture for missiles.

(32) **Guidance problems.** D. C. Romick and H. F. Lanier. *Aero Dig.*, **69** (1), 86, 88, 90, 92, 94 (*July*, 1954). General review of missile guidance problems.

(33) **The Deacon-pioneer in arctic space.** M. D. Ross. *Aero Dig.*, **69** (2), 26-28 (*Aug.*, 1954). The "Rockoon" is described which consists of a Deacon rocket carried beneath a "Skyhook" balloon to 70,000 ft. and fired. A final height of 300,000 ft. is reached. An important feature of this technique is the long time available for recording. Rockoons have mostly been used for meteorological measurements and cosmic ray research.

(34) **Missile guidance—why so little progress?** A. V. Sommer. *Aviation Age*, **22** (2), 16-19 (*Aug.*, 1954). A review of present methods of guidance and their drawbacks. Concludes that an inertial system is the only practical one for long-range missiles.

## RADIO AND ELECTRONICS

See also abs. no. 28.

(35) **New Raydist tracking systems.** C. E. Hastings and A. A. Budde. *Aero Dig.*, **69** (1), 56, 58, 60 (*July*, 1954). Continuous-wave, non-line-of-sight, heterodyne phase-comparison methods, allowing precision of the order of one foot are described. These systems are widely used for missile tracking.

(36) **Pulse transmitter for rocket research.** D. G. Mazur. *Electronics*, **27** (11), 164-167 (Nov., 1954). Telemetering equipment for Aerobee, providing 15 data channels. Sampling rate is 312·5 c.p.s., but one high-speed channel with a 1250 c.p.s. rate may be obtained. Equipment has performed reliably during 10 flights.

## ROCKET MOTORS

(37) **High-frequency combustion instability in rockets with distributed combustion.** L. Crocco and S.-I. Cheng. *Fourth Symposium* (*International*) *on Combustion*, pp. 865-880 (1953). Theoretical analysis of the growth of axial high-amplitude pressure waves which travel back and forth between injector face and nozzle. Spreading the combustion out over the length of the chamber gives a gain of stability over the case where combustion is concentrated at the injector.

(38) **Combustion instability in liquid-propellant rocket motors—a survey.** C. C. Ross and P. A. Datner. *Selected Combustion Problems, Butterworths Scientific Publications, London*. pp. 352-380 (1953). Three types of instability are discussed—low-frequency "chugging," high-frequency "screaming" and low-frequency "divergent"—and the pertinent literature reviewed. It is shown that the Nyquist criterion of stability could be applied successfully for predicting the dynamic behaviour of rocket systems if sufficient data on combustion were available. (46 *refs.*)

(39) **Combustion instability in solid-propellant rockets.** R. P. Smith and D. F. Sprenger. *Fourth Symposium* (*International*) *on Combustion*, pp. 893-906 (1953). Describes experimental work in which high-frequency combustion instability was encountered. Concludes that the excitation energy must come directly from combustion processes rather than from the kinetic energy of the gas flow.

(40) **Control system for rocket motors.** F. B. Halford, A. V. Cleaver and E. B. Dove. *U.S. Pat. No.* 2,659,197 (*Nov.* 17, 1953). Method of starting pressurized liquid-propellant rocket system.

(41) **Progress in rocket fuels.** R. W. Young. *Aero Dig.*, **69** (1), 96, 98-100 (*July*, 1954). Solid and liquid propellants and power plants.

(42) **Armstrong Siddeley Snarler.** *Flight*, **66**, 176-180 (*Aug.* 6, 1954). History of development and full technical details.

(43) **Armstrong Siddeley's Snarler.** *Aeroplane*, **87**, 180-184 (*Aug.* 6, 1954). Full details of the development, construction and operation of the Snarler.

(44) **More about the Sprites.** *Aeroplane*, **87**, 185-186 (*Aug.* 6, 1954). Sprite development and further technical details of the Super-Sprite.

(45) **Progress with rocket engines.** *Aeroplane*, **87**, 179 (*Aug.* 6, 1954).

(46) **Principles of rocket turbo-pump design.** C. C. Ross. *Aero Dig.*, **69** (3), 70, 72, 74, 76, 78, 80-84, 86-87 (*Sept.*, 1954). Derives equations which show effect of principal variables both in turbine and pump design and allow design of units of minimum weight.

## ROCKET PROPELLANTS

See also abs. no. 41.

(47) **The combustion of double-base propellants.** G. K. Adams and L. A. Wiseman. *Selected Combustion Problems, Butterworths Scientific Publications, London*. pp. 277-288 (1954). The available combustion data on pure liquid nitric esters and their vapours are discussed together with the properties of mixtures of nitric esters, with each other, with other compounds and with nitro-cellulose. Some relations between rate of burning, chemical structure and heat of explosion are brought out. Some similarities are shown to exist between the combustion behaviour of double-base propellants and mixtures of liquid nitric esters. (10 *refs.*)

(48) **The mechanism of combustion of solid propellants.** R. D. Geckler. *Selected Combustion Problems, Butterworths Scientific Publications, London.* pp. 289-339 (1954). Review of theoretical and practical knowledge of normal and vibratory combustion. Erosive burning is also dealt with. (52 *refs.*)

(49) **Solid propellants.** C. E. Bartley. *Aero Dig.*, **69** (1), 50-51, 54 (*July*, 1954). General review—simplicity, economy and ease of handling are main recommendations for solids.

(50) **Liquid oxygen for rocket engines.** *Aeroplane*, **87**, 187-188 (*Aug.* 6, 1954). Production, handling, performance and design, and cost of liquid oxygen as oxidant.

(51) **Properties of hydrogen peroxide.** *Aeroplane*, **87**, 189-190 (*Aug.* 6, 1954). Discusses properties, materials of construction, storage and future applications. (5 *refs.*)

### ROCKET PROPULSION

(52) **Relation of force, acceleration and momentum for a body whose mass is varying.** H. W. Sibert. *J. Aero. Sci.*, **20** (2), 141-142 (*Feb.*, 1953).

(53) **Topolographical preparations for artillery by the method of flare rockets.** G. Birardi. *Boll. Geod. Sci. Aff.*, **13**, 255-268 (*July-Aug.-Sept.*, 1954) (*In Italian*). Method of observing and determining enemy positions by use of rocket-borne flares.

## REVIEWS

### Exploration of the Moon

(Illustrated by R. A. Smith, text by A. C. Clarke. Published by Frederick Muller Ltd. 112 pages. 18s. net)

There have been, as is candidly stated on the dust cover of this work, many books about space travel. Readers will probably have sighted most of them and might, by now, be thinking that there is, for the moment, little new on the subject that can be written.

It will take no more than a quick glance through *Exploration of the Moon*, to realize that this is not so.

Written by A. C. Clarke and lavishly illustrated by R. A. Smith, nearly every page contains something new and of interest. The book divides the Conquest of the Moon into four phases: the establishing of the first orbital rockets; the initial approaches to, and landing by robot vehicle on the Moon; the first manned landing and early exploration; and the remoter events likely to materialize if a lunar colony is ever established.

There are 45 full-page drawings, including 8 in colour. Of the latter two deserve special mention; one shows a breath-taking view of an eclipse as seen from the Moon, and the other depicts a view inside a lunar city of the remote future. Here the slender trees seem badly proportioned—until one remembers the low gravity of our satellite.

The text takes the form of expanded captions; each page describing events in the facing illustration. The living in low gravity for extended periods might produce muscular atrophy and the return to the "6g" conditions on Earth unendurable or even fatal, and because of this the page opposite, an illustration of a Lunar Gymnasium, describes the need for such institutions on the Moon. Here, Clarke points out, if the air pressure was kept at the same value as on Earth, one could fly with suitable wings. Thus the conquest of the Moon is likely to make possible the fulfilment of a dream even older than that of space travel!

But it is the illustrations themselves that provide the main excitement in this book. They will provide interest during many evenings for a long time to come. M. F. ALLWARD.

### The Boys' Book of Space

(By Patrick Moore, F.R.A.S., with illustrations by A. L. Helm. Burke Publishing Company, London. 144 pp. 7s. 6d.)

The author has produced an outstanding book, containing a vast amount of information, presented simply, and in a most interesting manner.

The subject is introduced by a brief historical survey of astronomy from earliest times, followed by a concise outline of modern astronomical knowledge. From astronomy, the reader is led easily to the conception of escape velocity; and the principles of rocket flight, including the step rocket, are clearly expounded.

Four chapters are devoted to descriptions of possible future flights to the Moon, and to other planets of the solar system, in the course of which the various problems and dangers which may arise are discussed.

The illustrations are numerous and good, including many photographs of research rockets and astronomical subjects ranging from the Moon to the extra-galactic nebulae.

The book is to be commended specially for the complete absence of fantasy or over-dramatization; in general, the reader is presented with facts which lead him gradually to the conclusion that space travel is certainly possible, and may well be imminent.

A chapter on extra-galactic nebulae at the end of the book appears rather out of place, since no attempt is made to suggest that travel to them will ever be possible. This subject would be better placed at the beginning of the book, together with the chapters dealing with purely astonomical matters.

An intelligent boy of ten or over would find this book as thrilling as any adventure story, and in reading it would amass a considerable amount of useful information. If Father opens it first, however, he will certainly not stop until he has read it from cover to cover. J. LINDSAY.

### The True Book about Space Travel

(By William Temple. Published by Frederick Muller Ltd., London, 1954. 144 pp., 26 drawings and diagrams. 6s.)

It used to be said that to appreciate the exhibits in the Dome of Discovery the viewer needed to be of at least Ph.D. standard. While this is not necessary to appreciate William Temple's book, the "teenager" for whom it is intended will certainly need to be able to read!

No concessions are made in the form of large glossy coloured plates, and in fact it is not clear what point is intended to be made by several of the sketches. However, it is very good value for the price, and three pre-Ph.D. thirteen-year-olds who were asked to act as assistant reviewers enjoyed the book and found it easy to follow.

The text follows what may now almost be called "classic" B.I.S. exposition of the subject in a very readable way and does not exaggerate the military importance of the subject as some other writers have done. I know of one reader of this book who in preparation for his future trip to Mars has been inspired by the sketch on p. 121 to try to find some beavers and to explain to them that we live on the third planet out from the Sun! He has not yet found any beavers locally and is now going to try on his hamsters.

In conclusion, any B.I.S. member might well give a copy to a young nephew, provided he sends with it a note to explain clearly the difference between "mass" and "weight" and to point out that a shell leaving a gun muzzle will not travel in a straight line however fast it is fired. JOHN SIMPSON.

# CORRESPONDENCE

## Questions of Space

SIR,

As a consequence of reviewing J. N. Leonard's book "Flight into Space" in an aviation journal, I became involved in an entertaining correspondence which, however, was so far outside the realm of practical present-day aviation that it was deemed more suitable for publication, if at all, elsewhere than in the journal where the review appeared.

Mr. Leonard had said (page 78) that a weightless passenger in a space ship, falling asleep while floating in the weightless air of the cabin, would propel himself across it by the jet effect of the breath from his nostrils; but I questioned this by asking if there would not be an equal and opposite effect every time he breathed in.

The first result was a letter from a German engineer, Mr. Jos. Reder, of Heidelberg, who wrote that "breathing out air will give a stronger repulse than taking in the air because of greater pressure difference." If that were not so, he added, "no pulse-jet would work, at least no pulse-jet with aerodynamical valves." Actually, in quiet breathing, one takes longer to breathe out than to breathe in, which suggests that the airspeed through the nose, and therefore the pressure difference, must be greater when breathing in. This may be because little effort is normally needed to breathe out, as the elastic tissue in the lungs does most of the work; in breathing in, on the other hand, one's muscles have to work against this elasticity as well as against aerodynamic friction in the airstream.

Another criticism came from Mr. M. J. Catherwood, of Cambridge, who pointed out that "in the respiratory process, air is inhaled, oxygen extracted to combine with carbon and hydrogen in the body, and the waste products, carbon dioxide and water vapour are, with unused air in lungs, exhaled. The mass exhaled will thus be greater than that inhaled." One molecule of oxygen, with a molecular weight of 32, will either combine with carbon to give a molecule of carbon dioxide, of weight 44, or with hydrogen to form two molecules of water, each with a molecular weight of 18. Of course he was right, and he added two pages of mathematics which did not, however, give any definite value for the passenger's net airspeed across the cabin.

So, Mr. Catherwood concluded, "our hypothetical space sleeper would thus slide gently to and fro, powered by his twin orifice pulse jet, with suction intake air, and efflux mass flow increased by fuel injection and heating, until rudely awakened by his head striking some part of the cabin." Presumably he would then execute a manoeuvre equivalent to that of turning over in bed, and settle down again (if you can call it "down") for another forty winks before being rudely awakened once more by contact with the opposite wall.

But we have still not quite reached the final solution of this pressing problem, because the jet from the sleeper's nostrils does not pass through his centre of gravity, but is directed obliquely forwards and "downwards." So his body would actually rotate slowly round some point in space behind and beyond his feet, and its path would not be a circle but an ever-widening spiral. The poor fellow would still fail to enjoy an uninterrupted night's sleep, and it is a nice mathematical problem to work out his point of first contact, complete with Estimated Time of Arrival.

However, not to worry: any sensible space-sleeper would strap himself in his bunk to ensure a good night's rest.

This was not the end of the correspondence, however. From the R.A.F. in Shropshire came a letter from L.A.C. A. Taylor, taking me up on another point of criticism of Mr. Leonard's book. It was there stated (page 208) that vegetation on Mars would extract all the carbon dioxide from the atmosphere, in the absence of animals to put it back. I said that, on the contrary, it would find its way back when the plant, during decay, re-combines with the oxygen it produced by photosynthesis during its lifetime.

Mr. Taylor, in his letter, objected that no oxygen has been detected in the Martian atmosphere. However, Dr. H. Strughold, head of the U.S. Department of Space Medicine, has thought of a way out; in his recent book *The Green and Red Planet*, he suggests that the Martian plants keep all their manufactured oxygen within their own tissues, so as to use it again for respiration. He could have added that the remaining oxygen should be just sufficient to enable the plant to decay by oxidation after death.

Another point raised by Mr. Taylor in a further letter was that there is probably insufficient water on Mars for all the supposed vegetation to feed on. The only possible way round this objection, as far as I know, was brought out by two research workers in Arizona, Drs. Bodil and Knut Schmidt-Nielsen, during a "Symposium on the Biology of Hot and Cold Deserts" held in London in September, 1952. They discovered that the kangaroo rat feeds on dry seeds and drinks nothing, yet it gives off a substantial amount of water by evaporation and excretion. Their obvious conclusion is that Nature has given it the power to manufacture water chemically within its own body. So perhaps Martian plants could do so too.

In view of this, it is some satisfaction to the more convivial sections of the human race to know that Nature has not yet devised a means of introducing alcohol into the blood stream without its having first to be imbibed through the mouth.

A. E. SLATER.

Dunstable, Bedfordshire.

## The Adventure of Space Travel

SIR,

The purpose of this letter is not to complain about Mr. Neumark's review of the above book, for I am in agreement with the few criticisms he raises, and can think of others on which I shall keep silent! It is intended purely as an explanation of the sins of omission.

The production of any book is a matter of co-operation between author and publisher, and while the former is responsible for the text and other material it contains, the publisher, who bears the financial responsibility for the venture, must obviously have an important say in deciding the size and make-up of the book, on which will depend the cost of production, and hence the selling price.

In the case in question, the manuscript I prepared contained 65 full-page plates (including all those suggested by Mr. Neumark), of which only some 16 remain. These were selected partly on my insistence that some could not be left out and partly by the publisher selecting ones with some sales pull. I had drawn three maps—of the Moon, Mars and Mercury—but only one was used (not of my selection). Tables of data had been prepared as an Appendix, but were omitted. If these changes had not been made, I suppose that the selling price might have been 15s. instead of 10s. 6d., which would reduce the number of purchasers, bad from the viewpoint of propaganda for astronautics.

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